P A T E N T D U C T U S A R T E R I O S U S

A clinical study of One Hundred and Ten Cases,
Seventy of which were submitted to operation.

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PATENT DUCTUS ARTERIOSUS.

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PATENT DUCTUS ARTERIOSUS

INTRODUCTION

"Among recent therapeutic advances" is the "fascinating chapter of co-operation between medical man and surgeon in the recognition of and the treatment of the Patent Ductus Arteriosus and its various complications." So wrote Gross in 1951 - the surgeon who some twelve years previously had been the first to ligate successfully the Patent Ductus Arteriosus, thereby writing the opening pages of this fascinating chapter, the introduction to which had been written some forty years earlier by George Gibson of Edinburgh (1898, 1900, 1906).

In no field of medicine is such co-operation between physician and surgeon needed more than in the field dealing with congenital malformations. Until recently, foetal malformations formed the hard core of what was regarded as unavoidable and inevitable neonatal mortality and morbidity, the cause of which was unknown and regarding which, with the exception of conditions such as hare-lip, cleft palate, spina bifida, which were obviously amenable to surgery, little could be attempted in the way of radical therapy. Thirteen years ago such was the state of congenital malformations of the cardiovascular system. Little was known regarding their causation and no active surgical therapy had been undertaken.

It was perhaps natural that Patent Ductus Arteriosus should be the type to be selected for the first attempt. The existence of the Ductus had been known for almost two thousand years, being first described by Galen (c. A.D.131-200) as a small vessel uniting Pulmonary Artery and Aorta in foetal life which subsequently closed after birth, though it is probable that his deductions may not have been based on dissection of the human body, which was at that time illegal, but on dissection of the Barbary Ape (Guthrie, 1945). Little more was learned about the Ductus until Harvey in 1628, in his argument regarding the circulation of the blood through the lungs, deduced that in foetal life the flow of blood through the Ductus must be from Right Ventricle to the Aorta. Thereafter, examples of persistent patency of the Ductus Arteriosus were described by several observers. With the classical description of the pathognomonic machinery murmur by Gibson in 1898, reiterated forcibly in 1900 and 1906, the diagnosis of the typical case of Patent Ductus Arteriosus was no longer in doubt. Munro in 1907 suggested the possibility of surgical ligation and demonstrated a surgical approach through the sternum in the cadaver, but fully thirty years were to elapse before ligation was successfully accomplished (Gross and Hubbard, 1939), the first attempt in 1938 (Graybiel, Strieder and Boyer, 1939) being unsuccessful. This successful ligation by Gross (Gross and Hubbard, 1939) has been a great stimulus to physiologist, physician

and surgeon alike, and in this way has been the start of a new era in the further understanding and elucidation of the problems of not only the Patent Ductus Arteriosus but of all types of congenital heart disease.

THE DUCTUS ARTERIOSUS.

Anatomy and Physiology.

The Ductus Arteriosus in foetal life is a short vessel arising as a direct continuation of the Pulmonary Artery and joining the Aorta at a point just distal to the origin of the left Subclavian Artery. It is approximately 1cm. long and 0.5cm. wide at birth (Noback and Rehman, 1941), thus approximating in calibre to the arch of the Aorta. Jager and Wollenman (1942) found the average measurements to be rather less. In their series the average length was 0.8cm. and width 0.3cm., but they had fixed their specimens before measuring. In a series of sixty postmortem examinations of stillborn babies and infants dying below the age of 48 hours (excluding premature infants) observed by the writer, the average length of the Ductus in the fresh, unfixed state was found to be 1.1cm. and the average diameter 0.36cm., which is in agreement with the above observers.

In the foetus the Ductus is an essential pathway since, although the pulmonary circulation is not entirely negligible (Barclay, Franklin and Pritchard, 1944), it enables most of the blood reaching the Right Ventricle to pass directly to the

Aorta. At birth, with the expansion of the lungs and the opening up of the pulmonary circulation, this pathway is no longer needed and the Ductus normally closes. The evidence is that this occurs within a few minutes following occlusion of the Umbilical Cord. This has been shown clearly by Barclay, Franklin and Pritchard (1944) by means of radio-opaque injections into the Anterior Caval Vein of the sheep foetus. Before the Umbilical Cord is tied, the contrast medium can be seen passing freely through the Ductus Arteriosus to the Descending Aorta as well as into the Pulmonary Arteries. Four minutes after the Umbilical Cord has been tied, a second Caval injection produces no shadow in the Descending Aorta, showing that the Ductus has now functionally closed. In the healthy, vigorous animal this appears complete and final, and only where there has been a general deterioration in the condition of the foetus has the channel appeared to reopen.

Although this functional closure thus occurs rapidly and immediately (and one may presume that this occurs in the human infant also), it is, however, some weeks later before complete anatomical closure occurs. In the human the actual time varies widely. The earliest age at which the Ductus has been seen to be anatomically closed in the writer's experience is 17 days, though between three and four months would appear to be the commonest time for complete closure to occur.

Theories regarding closure.

Many have been the theories to explain this immediate closure of the Ductus Arteriosus following birth but most have not been supported by experimentally observed facts. These have been summarised and discussed by Ballance and Edmunds(1891) Wells (1908), and more recently by Jager and Wollenman (1942) and Kennedy and Clark (1942).

It has been suggested that expansion of the large bronchi at the onset of respiration compresses the Ductus.

Distension of the Pulmonary Artery and Aorta with blood may compress the Ductus.

In the "competition for space" initiated by the onset of breathing the Thymus may compress the lung and this in turn compress the Ductus against the left Bronchus.

Thrombosis may occur in the lumen of the Ductus.

The presence of a valve-like structure at the aortic end of the Ductus has been postulated which would prevent bloodflow from Aorta to Pulmonary Artery which would otherwise occur with the change in pressures in the great vessels following birth.

The angle at which the Ductus enters the Aorta may be significant.

Experimental work regarding closure.

Experimental work has, however, been carried out by Kennedy and Clark (1941, 1942) to investigate this problem. Using guinea pigs, they have confirmed that there are two main phases in the closure of the Ductus :-

1) Active muscular contraction of the wall of the Ductus which takes place over several minutes and following which the Ductus remains closed (This is the stage demonstrated by Barclay, Franklin and Pritchard (1944) in the sheep foetus.).

2) Replacement of this muscular tissue in the wall by fibrous connective tissue (This takes about one month in the guinea pig.).

These workers have investigated various stimuli which may provoke this primary contraction and have found that the following do so :-

1) Mechanical or electrical stimulation of the wall or nearby tissue,

2) a rich oxygen supply by breathing or intermittent inflation of the lungs with air or oxygen,

3) a rich oxygen supply by injection of oxygen into the Umbilical Vein without inflation of the lungs,

4) injection of Adrenaline,

5) mechanical stimulation of the Carotid Sinus,

6) following brisk haemorrhage.

These workers also showed that these mechanisms were independent of nervous pathways, as interruption of all known pathways between the Ductus and the Central Nervous System failed to prevent closure by these stimuli.

It would appear that under physiological conditions, the most important factor is the intake of oxygen (i.e. the onset of respiration). Other factors, probably of importance, are the changing pressures in the cardiovascular system with the

opening up of the pulmonary circulation and the rise in pressure on the left side of the heart.

Following this primary closure, there is gradual obliteration of the lumen and replacement by fibrous tissue. Jager and Wollenman (1942) describe the Ductus Arteriosus as having a well defined elastic lamina except in several places where there are low intimal mounds composed of smooth muscle and fine elastic fibres arising from the internal elastic lamina. Anatomical closure is effected largely by increase in size and number of these intimal mounds. These later become replaced by collagen and finally by fibrous tissue. These workers, however, found that many variations in histological structure from this described pattern may occur. This possibly explains the diversity of findings by various previous workers.

THE PATENT DUCTUS ARTERIOSUS.

The theories regarding the stimulus to normal closure have been briefly reviewed above and naturally lead to a discussion of those factors which are at work when the Ductus fails to close in the normal way. The fault may lie either in failure of the primary closure or in the later obliteration. Those which spring to the mind most readily as warranting further investigation are

abnormal influences at birth particularly with regard to the establishment of satisfactory initial respiration;

the influence of mechanical factors such as abnormal arrangements of the Ductus Arteriosus

and concomitant abnormalities of the heart and great vessels;

the rôle of heredity.

These, however, will be discussed at a later stage (Page 288)

Anatomy and Physiology.

The Patent Ductus Arteriosus, as seen at operation, is in most cases a relatively large vessel, averaging about 1cm. in diameter in children and 1.5cm in adults. It is usually rather less long than it is wide, thereby differing from the Ductus as seen in the newborn.

Gerhardt (1867) has classified the Ductus anatomically as falling into four main types :-

1) the cylindrical, which is the usual type seen at operation,
2) funnel shaped with apex towards Pulmonary Artery,
3) window type or stomal,
4) Aneurysmal type.

Physiologists have been greatly stimulated by the advent of successful ligation which has enabled observations to be made in vivo in man. The mechanical effects of the Patent Ductus on the heart have been demonstrated and correlated with the physical findings. Eppinger, Burwell and Gross (1941), investigating six cases subjected to operation by Gross have proved that the shunt in the Patent Ductus is from Aorta to Pulmonary Artery (the reverse of the foetal state), and they have estimated that the blood shunted amounts to 45% to 75% of the

blood pumped out by the Left Ventricle into the Aorta. The Left Ventricle (which pumps peripheral flow plus shunt) therefore has to pump two to four times the amount that the Right Ventricle does (which pumps blood from periphery only). With this degree of shunt, it is not surprising that secondary effects on the heart are observed, i.e. enlargement of Left Ventricle due to the increased output and engorgement of the Pulmonary vessels due tothe increased flow in the Pulmonary circuit (Eppinger and Burwell, 1940). More recent work with the use of the intracardiac catheter has confirmed shunts of the above magnitude in many cases prior to operation and without the possible fallacy caused by the introduction of the anaesthetic at thoracotomy. (Cournand, Baldwin and Himmelstein, 1949) (Wood, 1950)

Experimental Physiology.

Eppinger, Burwell and Gross (1941) have also reproduced a similar situation in dogs by making an Aortic-Pulmonary Artery communication very comparable to a Patent Ductus Arteriosus in that in each case the flow was toward the Pulmonary Artery as in the human Patent Ductus and in each case the flow was more than 50% of the output of the Left Ventricle. When they did this, they found that one of two situations might develop :-

a) The Left Ventricular output might increase so that the peripheral flow remained as before, or

b) The Left Ventricular output might not increase to the same extent and the flow to the periphery be

actually diminished.

They also found that in two out of three dogs the pulmonary pressure rose following the making of the anastomosis and in the same number there was a rise in blood volume. They concluded on the basis of these animal experiments that the patient with the large Patent Ductus must either suffer a decrease in the blood supply to the organs supplied by the peripheral circulation, or else there must be an increase in output and therefore in work on the part of the Left Ventricle. In their investigations, all six human cases belonged to the latter category.

Leeds (1942-43) in a similar series of experiments on dogs produced an average flow of 46% of the output of the Left Ventricle through the artificial "Ductus", thus producing a situation comparable to that in the human case. He also investigated the effects of closing such a "Ductus" and found there was an immediate rise in the blood pressure in the Aorta; a slowing of the pulse, which he attributed to the cardio-inhibitory reflex mechanism mediated by the Vagus Nerve and Carotid Sinus, and possibly also to the suddenly decreased output of the Left Ventricle; no essential change in the Blood Pressure in the Pulmonary Artery; and a decrease in the cardiac output of both Ventricles. It will be of interest later to compare these findings with those at operation when the Ductus Arteriosus is ligated.

THE PROBLEM.

As a measure of the magnitude of the problem of Patent Ductus Arteriosus, Keys and Shapiro (1943) estimated that there were then approximately 20,000 persons suffering from Patent Ductus Arteriosus in the United States.

Abbott (1936) found the incidence to be 92 cases in 1,000 post-mortem cases of Congenital Heart Disease. By 1943, Keys and Shapiro found in the Literature 67 cases over the age of 17 years which had been confirmed at autopsy. 57 of these they considered to be typical cases of Patent Ductus. To this they added (1943) a clinical series of their own of 51 cases, increased to 62 cases the following year by Shapiro (1944), who concluded that cases over 40 years were rarely seen. They considered the expectation of life to be reduced by about 25 years, the causes of death being Subacute Bacterial Endarteritis in 41% and congestive failure in 28% of cases.

In 1945, Gilchrist published his Gibson Lecture of the previous year and stressed the need for a better understanding of the natural process of the disease. He reviewed 28 cases at this time, subsequently increased to 40 (1946) and later to 80 (1948). Other British series include those by East (1945), Hunter (1945) and Sellors (1945). Benn (1947), in a series of 40 cases, doubted the justification for surgery, as had Wilson and Lubschez

(1942), whereas Gross and Longino (1951), with experience of 412 cases treated personally, believe that operation is indicated in practically every case. Similarly, Mannheimer (1950) believes surgery should be undertaken in all. Welti and Koerperich (1948), after being initially in doubt as to the merits of surgery, followed 34 cases ~~aged~~ from 5 to 20 years and after reviewing their results felt that surgery had a place in the treatment of this malformation.

There are thus many problems still awaiting an answer.

Firstly, Aetiology. What are the factors which bring about the normal closure of the Ductus and why in certain cases does it remain open? What is the evidence regarding the influence of heredity and/or environment?

Secondly, Natural History. What is the life story of the case of Patent Ductus? Before we can assess surgery completely, we must know more of the natural course of the disease. Why do we appear to see far more cases in childhood than in adult life? Does the Ductus in many cases close spontaneously? Do we cease to recognise these cases clinically? (Benn, 1947) Do we fail to recognise them in adult life and do we miss them at Post-Mortem?(Shapiro, Keys and Violante, 1941. Gilchrist, 1945). What is the prognosis of the case which develops symptoms in childhood and, equally important, what is the prognosis of the case which survives virtually symptom-free to early adult life?

Thirdly, what are the results of operation, particularly from the long term aspect?

Finally, and dependent on these two latter findings, what is the place of surgery in cases of Patent Ductus? Should it be reserved for selected cases? If so, which? Should it be advised for all?

Not all these questions can be answered as yet, but with these problems in mind, this Series is proferred as a link in the chain which is at present being forged in the elucidation of the Natural History of Patent Ductus, and in the estimation of the place of surgery in this condition.

THE MATERIAL

It has been felt that much of the literature regarding Patent Ductus Arteriosus, particularly that based on pathological studies, is overweighted with the unique and the exceptional (Gilchrist, 1945), and is probably over-pessimistic in that it does not take sufficient account of survivors. Even clinical series from hospital are probably mostly overweighted by cases referred because of symptoms. Benn (1947) in an effort to overcome this last objection has divided his series of 40 cases into two sections (1) local cases, which includes all types of cases, (2) non-local, which have mostly been referred on account of symptoms, and he compares and contrasts these two groups. Unfortunately this sub-division renders his numbers rather small. The length of time that a series is under observation is also of importance as this may alter the author's impressions regarding the course of the disease (Welti and Koerperich, 1948).

COMPOSITION OF THE SERIES.

This series, consisting of 110 cases, has not been sub-divided other than into age groups, as it is felt that taken as a whole it represents a fair cross-section of cases of Patent Ductus, with the exception perhaps of the very youngest age group. This series has not been composed of selected cases chosen for their interest but consists of the first 110 cases seen by the writer in hospital practice

between the years 1944 and 1951.

Criteria for inclusion in the series.

Criteria for inclusion in the series are that the case has been examined clinically and the diagnosis of Patent Ductus Arteriosus confirmed

a) by post-mortem examination,

b) by operation, or

c) by physical signs which leave no doubt as to the diagnosis (As a measure of the standard of accuracy of diagnosis, 70 cases have been submitted to operation without error).

Most of the cases were referred by the Child Welfare Department of Edinburgh, by the School Medical Service, or found on routine examination at the hospital Ante-natal Clinic. In addition, the series includes most of the cases referred locally because of symptoms and also a small number from a distance who came to Edinburgh specifically for cardiac surgery. They thus constitute a fairly representative sample of symptom-free and of disabled cases.

The series covers a wide range of ages, the youngest seen being nine months and the oldest 64 years. Figure I shows the range and the number of cases seen in each decade. This Figure also stresses the large number of cases seen in childhood (58 in the first decade, as compared with 15 in the third and one in the seventh). This is the more remarkable when one considers that this series has been seen in a general hospital (Royal Infirmary of Edinburgh) - not a children's hospital.

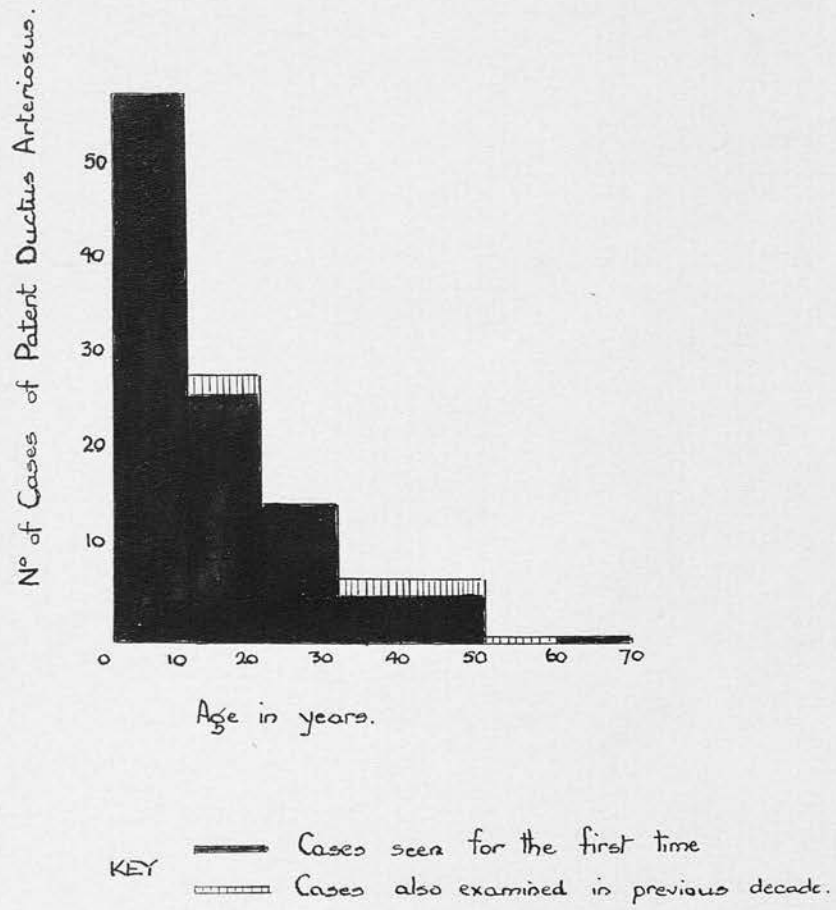


FIG. 1 Age Incidence of 110 cases of Patent Ductus Arteriosus, showing number of cases examined in each decade.

Note large number of cases seen in childhood compared with third and later decades.

The period covered by this investigation is 1940 to 1951, which is an additional advantage in this series as the observations have thus been made by the same group of observers over many years. Personal observations have been made between 1944 and 1951. I am much indebted to Dr. A. Rae Gilchrist for allowing me to use his case notes on 13 cases included in the follow-up which were not seen by me prior to ligation.

The series of 110 cases has been considered firstly as a whole as illustrative of the natural history of the disease.

An analysis of 70 cases, submitted to operation, has been made.

Finally, follow-up has been carried out on 64 cases surviving operation.

Of the 110 cases, four were seen on one occasion only. The others were seen repeatedly, many during a stay in hospital, in periods ranging up to ten years, as detailed below.

Similarly, the 64 cases surviving operation have been followed for periods ranging from a minimum of six months up to nine years in the case of the earliest survivor.

Details of the length of Follow-up before and after ligation are given in Table I, which follows :-

TABLE I - Detail of Length of Follow-up

(Before and after Ligation)

No. of years followed	Non-ligated cases	Cases following Ligation.
Over 10 years	1	0
9 years or more	2	1
8 years or more	2	2
7 years or more	4	2
6 years or more	5	8
5 years or more	7	12
4 years or more	9	18
3 years or more	19	25
2 years or more	28	39
1 year or more	47	56
Less than one year	53	8

SUMMARY OF MATERIAL.

Total number of cases	110	
Females	80	(72.7%)
Males	30	(27.3%)
Infected cases	9	
Submitted to Ligation	70	
Surviving operation	64	
Youngest in series	9	months
Oldest in series	64	years

OBSERVATIONS REGARDING AETIOLOGY OF PATENT DUCTUS ARTERIOSUS

It has already been pointed out that the fault in failure of normal closure of the Ductus may lie in

1) failure of the Ductus to close primarily immediately after birth, or

2) failure of the obliterative process which normally follows this.

Experimental work already referred to (Barclay, Franklin and Pritchard, 1944) would suggest that the initiation of satisfactory respiration in the newborn is of paramount importance for closure of the Ductus. Kennedy (1942) believes that it is interruption of the first phase in closure which is responsible for the condition of persistent patency of the Ductus Arteriosus.

In the search for factors in the aetiology of Patent Ductus, it was felt that a detailed investigation of the conditions attending each child's birth might be valuable. In addition, any adverse influences acting during the pregnancy have been noted, such as age and illness of the Mother.

Evidence of genetic influence has been looked for by study of the sex incidence, the presence of consanguinity, the incidence of other congenital abnormalities known to be genetic in origin, and the incidence of such congenital abnormalities in parents, siblings or offspring.

In 93 of the 110 cases, a birth history was obtained which appeared to be accurate and trustworthy. In the majority of cases, the delivery was at home but where it occurred in hospital confirmatory evidence has been obtained in most cases from the hospital concerned.

BIRTH HISTORY.

Of the 93 cases in which accurate birth histories were obtained, 37 were first pregnancies and of these 13 were abnormal. In addition, 21 other pregnancies were abnormal, making a total of 34 abnormal pregnancies (36.5%).

Abnormal Pregnancies.

Details of these abnormal pregnancies are as follows :-

a)	Instrumental delivery	12
b)	Breech delivery	6
c)	Prolonged labour (over 24 hours)	5
d)	Caesarean section	2
e)	Antepartum haemorrhage	2
f)	Maternal illnesses during pregnancy	9
	Hyperemesis 4	
	German Measles 1	
	Mumps 1	
	Jaundice 1	
	Severe "flu" (Not epidemic) 1	
	Femoral thrombosis and blood transfusion 1	

In some cases more than one abnormal factor operated, but as can be seen the majority of the

abnormalities (a) to (f) operate at the time of delivery. As a result, no fewer than 10 babies were distressed at birth.

State of the Child at Birth.

Case 17 Delivered by forceps on account of foetal distress (hospital record)

23 Mother was hypertensive. The baby was blue and shocked (hospital record)

39 Baby cyanosed after breech delivery (Mother's history)

55 Baby very blue for three days after forceps delivery (confirmed by Doctor)

70 Baby blue and needed resuscitation after 5-day labour (Mother's history)

84 Baby very blue after birth (Mother's history

95 Baby very weak after birth (confirmed by Doctor)

99 Baby weak and collapsed - "given up" for six days after 30 hours labour (hospital record

109 Baby blue following birth (Mother's history)

110 Baby pallid after birth - cord round neck (Mother's history)

The emphasis is thus on blueness following difficult deliveries, persisting for a few days and associated with general weakness rather than on attacks of blueness, which suggests that atelectasis was probably the chief underlying pathology accounting for the blueness.

Influence of Prematurity and Size of the Child.

Prematurity does not seem to play a part in

this condition. Only one child was premature and this child weighed 5lbs. at birth.

The birth weight was known accurately in 46 cases - and ranged from 5lbs. to 14lbs. Though the average weight was 7.7lbs., no fewer than 12 of the 46 weighed more than 9lbs. There are thus a high proportion of large babies in this series.

Maternal Illness During Pregnancy.

The nine cases of illness on the part of the mother during pregnancy are also of note.

Severe hyperemesis occurred in four, two being sufficiently severe to warrant admission to hospital. The other two cases in which hyperemesis was a severe feature of the pregnancy are also of interest in that they were sisters. In three other pregnancies in this family, all resulting in healthy normal boys, the Mother had no hyperemesis whatever.

The infections are also of interest. The case of German Measles (case 39) occurred at the first month of pregnancy, and resulted not only in congenital heart disease but also in deaf-mutism and an appearance suggestive of arachnodactyly.

Mumps occurred at the fifth month in case 31 and was a very severe attack. Patent Ductus was apparently an isolated defect in this case, as it was in case 16, whose Mother had a moderately severe attack of Jaundice when two months pregnant, and in case 58, whose Mother had severe "flu" when three months pregnant, although there was no epidemic at the time.

Other Abnormal Features.

Other abnormal features are that

5 were either preceded or followed by a stillbirth,

3 were either preceded or followed by a miscarriage,

1 was followed by hydatidiform mole (case 64),

1 was followed by abnormal twin pregnancy - one macerated and retained (case 26).

Parental Age.

In 63 cases where the age of the parents at the time of the child's birth was known with certainty, the average ages were as follows :-

Maternal	Mean	28.5 yrs.	Paternal	Mean	30yrs.
	Youngest	19 yrs.		Youngest	19yrs.
	Oldest	42 yrs.(2 cases)		Oldest	44yrs.

In 23 cases the Mother was over 30 at the time of the child's birth.

GENETIC INFLUENCES.

Consanguinity.

In no case was there evidence of consanguinity apart from one case where the great-grandparents had been cousins, but this is considered to be of no significance.

Sex Incidence.

As in most other series, females were found to outnumber males - the actual figures being :-

Females	80	i.e. 72.7%
Males	30	27.3%
Total	110	

Congenital Abnormalities Present in Addition to Patent Ductus.

Clinical examination of all cases revealed

18 with other developmental abnormalities, as follows:

Spina Bifida	5 cases
Haemangioma	3 "
Cervical Ribs	2 "
Hernia	2 "
Ventricular Septal Defect	1 case
Deaf-mutism	1 "
Blindness	1 "
Squint	1 "
Dermoid of Ovary	1 "
Mental Defect	1 "

Spina Bifida was not looked for routinely by X-Ray, but only where there was a history of Enuresis. X-Ray examination showed well-marked Spina Bifida to be present in five such cases. One case had required operation immediately after birth (case 40).

Deaf-mutism occurred in case 39 whose Mother had had a mild attack of German Measles when four weeks pregnant. The deafness in this case is almost complete and has existed from birth. Very high-pitched notes appear to be heard by this child, e.g. the screeching of parrots - the type of deafness thus agreeing with that described by Swan, Tostevin, Moore, Mayo and Black (1943) as frequently following German Measles in pregnancy.

Case 94 had been blind from birth - due to incomplete development of both eyes. There was no illness in the pregnancy in this case and no family history of blindness.

Case 100 had signs of Ventricular Septal Defect in addition to Patent Ductus Arteriosus.

The Dermoid of Ovary was found routinely at post-mortem examination and had not given rise to symptoms during life (case 70).

Congenital Abnormalities in Relatives.

Enquiries were made regarding the health of all brothers and sisters, and the siblings of 51 cases were examined personally.

The opportunity was also taken to examine the mothers who accompanied their child to the hospital (90 cases), and where possible the offspring of adult cases of Patent Ductus have been examined (16 cases).

a) Evidence of Congenital Heart Disease in Relatives.

1. Patent Ductus Arteriosus.

In three families a second case of Patent Ductus was found on examination of the rest of the family. Case 51 and case 107 are sisters. Both were born after precipitate labours. No other siblings and no family history of cardiac disease. Mother and Father both normal - no consanguinity.

Case 66 and case 106 are sisters. In both cases the Mother suffered from severe hyperemesis during pregnancy. Three brothers are normal and no hyperemesis was experienced during their pregnancy. There is no family history of cardiac disease. The Mother is normal; the Father was not examined. No consanguinity.

Case 36 has a brother (case 48) with Patent

Ductus also. An older sister died of congenital heart disease (cyanotic type). Mother and Father both normal - no consanguinity. The family pedigree is of interest :-

1st child - "blue baby", died aged 1 year four months following tracheotomy

2nd child - case 48, Patent Ductus

3rd child - stillborn

4th child - case 36, Patent Ductus

5th child - normal girl, aged 4 years at time of writing.

2. Other forms of congenital heart disease.

Case 36 has a sister who has a mild Pulmonary Stenosis.

Case 78 shows the presence of congenital heart disease in three generations. Her Mother was also under observation suffering from Auricular Septal Defect. Her own first child was a "blue baby" at birth and died shortly after (no post-mortem proof of type).

Case 41 had a sister who died of Subacute Bacterial Endocarditis superimposed on probable congenital heart disease, type unknown (evidence of home doctor).

Case 89 - her first child died aged one day of a blue attack (?congenital heart disease) - no post-mortem.

b) <u>Evidence of other Congenital Abnormality in Relatives</u>.

Spina Bifida (brother of case 4) confirmed by X-Ray

Congenital Pyloric Stenosis	(brother of case 9)
Cleft Palate	(sister of case 32)
Hirschsprung's Disease	(brother of case 105)
Talipes Equinus	(brother of case 70)
Clawfeet	(sister of case 65)
Meningocele	(brother of case 65)
Congenitally short Right Arm	(father of case 67)

There are thus twelve families (out of 107 families) in which there is definite evidence of congenital abnormality affecting more than one member of the family, either in the same generation or in two or more successive generations, and two families in which the evidence is suggestive though not proved.

SUMMARY OF EVIDENCE REGARDING AETIOLOGY OF PATENT DUCTUS ARTERIOSUS IN 110 CASES.

1. Ante-natal Influences

a) Infections	German Measles	1 case
	Mumps	1 "
	Jaundice	1 "
	"Flu"	1 "
b) Nutritional states	Hyperemesis	4 cases
c) Maternal age - over 30 years		23 "
average age 28.5 years		

2. Natal Influences

a) Abnormal delivery	28 cases
b) Neo-natal distress	10 "
c) Prematurity	1 case

3. Evidence in favour of Genetic Influence

a) Consanguinity	Nil
b) Sex incidence	72.7% female

Evidence in favour of Genetic Influence (contd.)

c) Developmental abnormalities

in addition to Patent Ductus 18 cases

d) Developmental abnormalities

in other members of family 12 families

Congenital heart disease (12 cases) 5 "

Other abnormalities (8 cases) 7 "

THE NATURAL HISTORY OF PATENT DUCTUS ARTERIOSUS.

SYMPTOMS.

Incidence of Symptoms.

In this series of 110 cases, 61 were referred on account of symptoms. The other 49 cases were found routinely in the course of examination as follows :-

Child Welfare and School Medical Examination	39 cases
Ante-natal Clinic	7 "
Routine check of Siblings of cases of Patent Ductus	2 "
Found incidentally (Sciatica)	1 case

On questioning, however, 93 of the total number were found to have symptoms and only 17 to be completely symptom-free. Of these 17 symptom-free cases, nine have been subjected to operation. There has been such improvement in five of these cases since ligation of the Ductus that their Mothers now realise that their children were handicapped before, although only slightly. They had been so well adapted that they were unaware of any disability. It was found in retrospect that four had been unduly tired and one a little breathless.

Thus, of this series of 110 cases, although only 61 were referred because of symptoms and 49 were found routinely, 98 have in fact been found to have symptoms (some very mild), and only twelve could be counted really symptom-free.

The ages of those symptom-free were one year three months, 4, 6, 6, 7, 8, 9, 16, 22, 24, 25 and 27 years respectively, which is of interest in that there is a relatively higher proportion of young adults symptom-free than of children (although the absolute incidence is reversed). Possible explanations of this are that

1) minor degrees of disability in childhood are forgotten, these becoming less as early adult life is approached; or

2) it may be that few with symptoms in childhood survive to adult life. There is some evidence to support both views.

Complaints.

The two leading complaints were tiredness and breathlessness on exertion, frequently present together, and in the child frequently difficult to distinguish accurately. Frequent colds and coughs came next in frequency. The following table gives the frequency in this series of most of the complaints associated with this condition.

Tiredness	57 cases	(53 plus 4 in retrospect)
Breathlessness on exertion	55 "	(54 plus 1 in retrospect)
Tiredness and breathlessness (combined)	32 "	
Recurrent colds and coughs	30 "	
Consciousness of the heart	15 "	
Occasional blueness	12 "	
Faints or "turns"	11 "	

Pains in chest	9 cases
Pallor	8 "
Swelling of ankles	7 "
Epistaxis	7 "
Enuresis	7 "
Difficulty in feeding	6 "
Undue sensitivity to cold	2 "
Haemoptysis	1 "
Hoarseness	0 "

The above do not include symptoms which are due to the infective element in Subacute Bacterial Endarteritis.

Analysis of Complaints.

Tiredness.

This was the most frequent complaint and though commonly associated with breathlessness (32 cases), it was nevertheless a complaint in 25 cases where breathlessness was denied. Of the 57 cases who complained of tiredness, 21 said they had always been more easily tired than their neighbours, and were unable to give an exact date of onset of this symptom.

Of the 36 cases where the onset was specified, eight were below the age of 4 years, including two babies who were said to go limp when feeding (case 38 and case 58), six developed the symptom at 4 years, 13 at 5 years, one at 11 years, one at 13 years, and seven in adult life. It is thus obvious that the strain comes below the age of six years, and few children develop symptoms of tiredness

if they survive entrance to school without doing so. The tiredness complained of took three main forms.

1) The child who was wanting always to be carried when out walking. Some of these may really be minor degrees of breathlessness on exertion, the child stopping short of breathlessness.

2) The child who played actively, and suddenly threw himself or herself down exhausted.

3) The child who took "tired turns" - with pallor and shadows under the eyes, needing an occasional day in bed in order to keep up with ordinary school activities (e.g. case 63).

It is of interest to note that of three cases with this complaint in childhood who have reached adult life, in two the symptom has persisted, while in one (case 21) tiredness has become much less marked since the age of 15 years.

Breathlessness on exertion.

Of 55 patients who complained of breathlessness, 41 developed the symptom in childhood and 14 in adult life. No adult gave a history of breathlessness on exertion in childhood which later disappeared. In six of the total of 20 adults with the complaint it had been present since childhood.

In one child (case 36) breathlessness was noticed as a tiny baby when feeding. The Mother noticed that she fed like an older sister who had been a "blue baby", and on this account took her to the Child Welfare Clinic at the age of three months, where

congenital heart disease was diagnosed, which later proved to be Patent Ductus.

Of the 41 children who suffered from breathlessness on exertion, 38 had developed the complaint by five years of age. In ten the complaint was graded as moderately severe. In seven of these the condition was complicated by chest trouble, chiefly recurrent bronchitis or bronchiectasis. Two with no chest trouble had evidence of a particularly large Ductus. The tenth case was complicated by mental defect.

It is evident from the above that recurrent bronchitis or bronchiectasis in association with Patent Ductus plays a large part in the production of the symptom of breathlessness in childhood, particularly when severe, and that while the size of the ductal shunt is of some importance, it is of secondary importance to the respiratory complication.

In eight adults breathlessness was graded as moderate to severe, as shown in Table II below :-

Case No.	Sex	Age of development of breathlessness on exertion	Subsequent History
71	M.	59yrs. Previously no complaint	Aged 64yrs. C.H.F. with Aur. Fib.
72	M.	49yrs. Slight	Aged 55yrs. early C.H.F. Death in epileptic fit
74	F.	46yrs. Slight	Aged 48yrs. severe C.H.F. with N.R.
75	M.	46yrs. Rapidly progressing	Severe C.H.F. with Aur.Fib. Death 48yrs.
76	F.	37yrs. Slight	Pregnancy aet.41yrs.- Grade IIb.

Case No.	Sex	Age of development of breathlessness on exertion	Subsequent History
73	F.	36yrs. Slight	Pregnancy aet.36yrs.- Grade IIb in puerperium.
79	M.	32yrs. Slight, associated with paroxysmal Aur.Fib.	Aged 38yrs. Relieved by restoration to N.R.
83	F.	23yrs. Rapidly progressing	Severe C.H.F. with paroxysmal Aur. Fib. and paroxysmal Tachycardia. Death at 23.

(Abbreviations:-
(C.H.F. = Congestive Heart Failure
(Aur. Fib. = Auricular Fibrillation
(N.R. = Normal Rhythm
(IIb. = cardiac disease, marked limitation of
(physical activity (N.Y.Heart Assn.1939)

Of the eight adults in whom breathlessness was a marked feature, all were in the fourth or later decades with the exception of case 83, in which the major condition was rheumatic and the Patent Ductus was a minor part of the pathology.

It is also noteworthy the frequency with which it is associated with abnormal rhythm (five cases out of the eight) - in four, auricular fibrillation - in one, multiple extrasystoles. The importance of the part played by rhythm is demonstrated by case 79, where breathlessness on exertion coincided with paroxysms of auricular fibrillation from the age of 32 years. With restoration and maintenance of normal rhythm by Quinidine at the age of 38 years, he has been relieved and is fit to undertake his work as chauffeur gardener again.

In the adult, the development of

breathlessness on exertion is a very unfavourable sign. In seven out of eight cases above cited it was followed by congestive heart failure. In two cases (75 and 83) severe congestive heart failure ensued in less than six months and death within two years. Two cases who were breathless on exertion, aged 36 and 37 years respectively, were Grade IIb in pregnancy following this. Three cases who were 46, 49 and 59 years respectively when they developed the symptom each developed congestive heart failure within six years. The only case which has not developed failure is case 79, in whom normal rhythm has been restored with marked improvement.

Severe breathlessness on exertion, whether in child or adult, is thus an important symptom. In the child it may be an indication that the Ductus is unusually large, but more commonly it is associated with recurrent chest trouble, which fails to respond adequately to therapy unless the Ductus is ligated. It is noteworthy that of 32 cases of Patent Ductus Arteriosus in this series, over the age of 16 years, not one gave a history of breathlessness on exertion other than slight in childhood. This is suggestive evidence that the prognosis for the child with moderate to severe breathlessness is poor.

In the adult, it is a serious symptom being associated in many cases with the development of abnormal rhythms and the forerunner of congestive heart failure in most cases.

Recurrent Colds and Coughs.

This is a complaint almost entirely confined to childhood, 29 children being affected and only one adult (case 21). These children appear to be unusually susceptible to sinus infections. Thirteen showed recurrent bronchitis, with in three cases bronchiectasis. Two suffered from recurrent collapse at right and left bases respectively. Recurrent attacks of Pneumonia were a feature in two cases.

Case 36 is a typical example :-

She was noticed to be breathless as a baby when she fed; had an attack of Pneumonia at three months; thereafter had recurrent attacks of chesty colds. Aged 5 years, had two attacks of Pneumonia within a year; was easily tired; too breathless to play. An X-Ray examination at 16 months showed the heart already displaced to the left; at 5 years a large heart and collapse at the left lower lobe, with possibly slight narrowing of the left bronchus.

With attention to sinuses and general measures the atelectasis at the left base disappeared but signs of bronchiectasis persisted at that base, and the heart remained displaced to the left. Eventually, she was considered fit enough for ligation and in 2½ years follow up since then there has been no recurrence of any acute respiratory infection. Signs at the left base are intermittent and minimal, and the breathlessness has entirely gone.

The persistence of these respiratory

infections and their resistance to therapy has made preparation for ligation a difficult and lengthy matter in these cases, ten of which have been ligated. It is difficult to account for the high proportion of respiratory infection in these cases. It cannot all be explained by the size of the shunt, as there are cases where the shunt appears to be large and yet there is no recurrent respiratory infection. Social conditions undoubtedly play a part. Most of these cases begin before the age of two years, and it is possible that early pressure on the left bronchus by the Patent Ductus and the enlarged Pulmonary Artery may give rise to areas of pulmonary collapse, which may be the starting point for bronchiectasis. This point is also suggested by the number of cases in which the heart appears displaced to the left on X-Ray examination.

Consciousness of heart.

a) Children:

Four children were noticed to have noisy hearts. Two were noticed by their parents when sleeping in bed with them.

In the third -(case 33)- the noise of the heart beating was said to be audible across the room (at eighteen months of age).

In the fourth -(case 45)- after severe exertion, the Mother said that she not infrequently heard the girl's heart beating while standing beside her.

In both the latter cases the Mothers

appeared reliable witnesses. Neither was confirmed by personal observation.

Three children (cases 46, 55, 67) were noticed about the age of 1½ years to have tachycardia sufficiently marked for their parents to consult a doctor regarding it.

Case 33 was noticed to have extrasystoles when attending nursery school at 3 years.

b) Adults:

Seven adults complained of palpitation. In three cases this was associated with abnormal rhythm (case 72 - multiple extrasystoles and cases 79 and 83- paroxysmal auricular fibrillation).

Of the four who showed normal rhythm, one (case 70) had a markedly overactive heart following exercise, one (case 29) felt his heart miss a beat after exertion but nil was noted while in hospital, two (cases 78 and 86) avoided exercise which produced palpitation and therefore nil was noted objectively.

Transient blueness.

Eleven cases showed this in early childhood:

Nine on exertion, especially in cold weather,

One when coughing or in a tantrum,

One when crying as a baby.

One case (75), aged 46 years, showed persistent cyanosis with polycythaemia (Arterial Oxygen Saturation 78.23%. P.C.V. 54%). Post-mortem showed a Patent Ductus of stomal type, the presumption being that there had been a shunt from Pulmonary Artery to Aorta at least terminally in this case.

It is possible that the transient attacks of blueness in the children, described above, were associated with temporary rises in pulmonary arterial pressure, e.g. in coughing, tantrums, etc., resulting in temporary reversal of shunt. On the other hand, in an already overloaded pulmonary circulation a slight increase may result in cyanosis without actually a reversal of flow.

Faints or "turns".

There was a history of these in eleven cases but in five it is probably merely incidental, as follows :-

Fits below 3 years of age	3 cases
Petit Mal (adult)	1 case
Faint (vasovagal)	1 case

In six cases, however, there appears to be a more direct relationship :-

Faints (recurrent)	2 cases
Dizzy turns	2 cases
Epileptic fits	1 case

The two fainting cases referred to above are case 28, who persistently fainted when knocked before ligation of Patent Ductus at age 7 years, but has not done so since; and case 56, who before ligation at age 4 years could produce a faint by breath-holding if annoyed with her Mother, but since ligation has been unable to do so!

These children appeared to have very sensitive cerebral vasomotor control, which was possibly related to their large pulse pressure.

Dizzy turns, complained of in cases 29 and 72, are more difficult to assess, and it is difficult to exclude a functional basis. In one, the turns were related to stooping (without change in Blood Pressure); in the other, to exertion.

Case 71 took occasional epileptic fits from the age of 53 years and finally died in an attack. Neurological examination during life was entirely negative between attacks. Unfortunately, no autopsy was carried out and so no definite cause for the fits ascertained. The occasional association of cerebral aneurysm with Patent Ductus is a possibility.

Pains in the chest.

Six children complained of pains in the chest associated with effort but in no case was it a major complaint, although in one (case 4) it was associated with mild congestive heart failure.

Three adults complained of pain in the chest - two on effort - but in neither case was the pain central; one in the cold felt a tightness across the chest. The evidence would suggest that pain in the chest in Patent Ductus is usually functional, prominence being given to the condition because of the known presence of congenital heart disease. No case of frank Angina was encountered.

Epistaxis.

Recurrent epistaxis was encountered in seven cases - all under 17 years - and occurred quite independently of Bacterial Endarteritis.

Enuresis.

Seven cases complained of this, and in four there was radiological evidence of Spina Bifida (cases 4, 53, 64 and 92). In addition, in one case (40) with no enuresis, the condition had been severe enough to warrant operation as a baby of one week old. There were thus five cases of Spina Bifida in the series.

It is of interest that two cases were said to be cured following ligation of Patent Ductus (cases 44 and 53), but whether this was due to improved general health or hospital training is doubtful.

Feeding Difficulties.

Reference has already been made to two babies who appeared to be very easily tired and to go limp when feeding (cases 38 and 58). In addition, one baby was not strong enough to suck the breast but managed satisfactorily on a bottle (case 102).

Case 36 was breathless and "fed like her older sister who had been a blue baby", to quote the Mother's words. Cases 46 and 52 suffered from repeated vomiting up to the age of 3 years and were difficult to rear on this account.

Undue sensitivity to cold.

This was noted in two cases (6 and 52).

Haemoptysis.

This occurred in case 33 at the age of 2 years. No cause, other than Patent Ductus, was found to account for this.

Hoarseness.

Hoarseness due to pressure on the Recurrent Laryngeal Nerve has been described, but was not encountered in this series.

Development of Subacute Bacterial Endarteritis.

This developed in nine cases, two at school age - aged 6 and 7 respectively - and seven between the ages of 16 and 32 years. This is discussed more fully on Page 226.

SUMMARY.

As has been noted by other observers, the commonest presenting symptoms are tiredness, breathlessness on exertion and recurrent colds and coughs.

In the pre-school age the condition is by no means symptom-free.

Ten babies were distressed after birth - one was pallid, due to the cord having been round the neck, nine were blue and needed resuscitation. "Blue attacks", as in cyanotic heart disease, were not described, though one baby was described as blue when crying and other little children were noticed to be transiently blue on exertion or when coughing or in tantrums.

Difficulty with feeding occurred in six cases and in four was probably due to breathlessness.

Recurrent colds and coughs, if going to be a troublesome feature, usually manifest themselves in this age group. Breathlessness in this age group was usually associated with recurrent respiratory

infection.

By school age, the chief complaint is tiredness. The first week at school is a good test. No fewer than sixteen cases in this series developed this symptom when they began school life at the age of 4 or 5 years. In only a few, however, was it severe enough to warrant attendance at a Special School (4 cases).

Breathlessness on exertion may be a troublesome feature in the school age group, usually having begun in the younger group and being associated with recurrent chest trouble.

Occasional symptoms at this age are transient blueness, fainting turns, epistaxis, and enuresis. School age is not exempt from the development of Bacterial Endarteritis, two cases aged 6 and 7 years respectively being seen in this age group.

In adult life, symptoms change little until over the age of 30 years, except that chest colds are less frequent, and symptoms generally less marked than in the child. In the absence of evidence to suggest gradual amelioration of symptoms between child and adult life, this would suggest a survival of the least handicapped. (Unfortunately, none in this series with symptoms have been followed through adolescence non-ligated as it was not felt right to withhold them from operation.)

Pregnancy is wellborne in the third decade, all twelve pregnant women being Grade IIa during their

pregnancies, with one exception (Case 87, with large shunt, who developed mild signs of failure towards the end of her pregnancy). Of five pregnancies in the fourth and fifth decades, only one was Grade IIa throughout pregnancy and puerperium. Three developed symptoms of failure after delivery.

Palpitation is a troublesome though not a serious symptom in a few cases (seven in this series, three of these being associated with an abnormal rhythm, the others with an over-active heart).

Young adult life appears to be the time when the case of Patent Ductus Arteriosus is at greatest risk from Subacute Bacterial Endarteritis - no fewer than seven out of nine cases in the series occurred between the ages of 16 and 32 years.

Over 30 years of age, the development of breathlessness on exertion has a more serious significance. In eight cases which developed this symptom in adult life, one associated with Auricular Fibrillation was relieved by restoration of normal rhythm, but the other seven all developed congestive heart failure within five to six years of the onset of the symptom, and three of these have since died.

CLINICAL FEATURES.

The account which follows of the clinical features found in Patent Ductus Arteriosus is based on repeated observations of the 110 cases by the same observers. The cases have been seen on the average annually, though some have been seen at more frequent intervals and others at rather longer intervals. Seven have been seen on one occasion only, but the remainder have been followed in periods varying from six months to ten years. Personal observations have been made over the past seven years.

CRITERIA FOR DIAGNOSIS.

Although it is appreciated that Patent Ductus may exist in the absence of the pathognomonic murmur, described so many years ago by Gibson (1898, 1900, 1906), nevertheless such cases form a small group, albeit an interesting one, and in the absence of catheter or angiocardiographic studies cannot be diagnosed with certainty. Gross and Longino (1951) estimate that 97-98% have typical murmurs. In this series, in which no catheter or angiocardiographic studies have been made, the diagnosis of Patent Ductus Arteriosus has not been made in the absence of the Gibson Murmur unless there is operative or pathological proof of the presence of a Patent Ductus Arteriosus.

All observers are agreed that the classical Gibson Murmur is a rumbling, vibratory continuous murmur becoming louder towards the end of systole and appearing to envelop the second sound, which is usually

split and the pulmonary component markedly accentuated. In the classical case in childhood, the murmur is maximal in the second left intercostal space close to the sternum or below the sternal end of the left clavicle, but in the adult, it may be found more and more to the left of the midline (Gilchrist, 1945). The intensity of the murmur varies from case to case. Gilchrist (1945) has described three main grades :-

a) With faint murmur ("humming top")

b) With moderate murmur ("churning" or "machinery")

c) With loud murmur ("rolling thunder")

To this may be added

d) With very loud murmur ("painful to the ear"), which is really a sub-division of (c).

CLINICAL STUDIES.

Murmur.

The above classification of intensity has been followed in this series. In addition to classifying the murmur according to intensity, particular note has been made of cases where the characteristic murmur has been absent, variable or has gradually developed.

In five children, the gradual development of the typical continuous murmur has been observed.

In two, the continuous murmur was noted to vary from day to day.

In two adults, it was on occasions absent.

In one adult it was consistently absent.

In the other hundred cases, the murmur was considered at all times to be sufficiently

characteristic to be diagnostic. The site of the murmur, the presence of an accompanying thrill, and the presence of other murmurs - either organic or functional - have also been noted.

Blood Pressure Studies.

Blood Pressure readings have been made under reasonably basal conditions. In the case of inpatients, the blood pressure has been taken at the same time each day by the same observer; in the case of outpatients with the patient lying quietly at rest, again by the same observer. In the child, where the standard cuff is too large, the bag has been folded lengthwise as recommended by Gilchrist (1945) before being applied to the arm.

Readings have also been made of leg blood pressure with the subject prone, the bag above the knee, and the observer auscultating in the popliteal space.

It has been found that once the child or adult became accustomed to coming to hospital and used to having the tests done, the Blood Pressure readings have been very consistent from one observation to the next.

In addition to these Blood Pressure studies, Blood Pressure readings following exercise have also been made (Bohn, 1938). In the case of children, this has been repeated on several occasions and again, once the child understood the test and co-operated, the readings have been very consistent. The technique adopted has been modified in the light of experience

and will be described and discussed in the appropriate section (Page 73).

Nutrition, and other Pathology.

Besides these observations on the state of the cardiovascular system, the nutritional state has been noted, a record of the height and weight being kept at each visit.

Any other Pathology present, particularly the state of the Respiratory System, has been investigated.

Radiology and Electrocardiography.

Teleradiograms have been made at each visit, the views ordinarily taken being postero-anterior, right and left anterior oblique. Screen examination was carried out as required - in all cases before and after operation, and repeated where there were unusual features.

The Electrocardiogram, as originally carried out, consisted of Leads, I, II, III, with in addition sternal and apical leads (CF2 and IVF), but since 1948 12-lead electrocardiograms have been the rule, with three standard leads, three unipolar limb leads and six unipolar precordial leads.

Sub-division into Age Groups.

For the purpose of analysis of the above clinical features - Nutrition, State of the Cardio-Vascular System, Other Pathology, X-Ray of Heart, Electrocardiogram - the series has been sub-divided into four groups as this facilitates comparison being made with satisfactory standards. It also

helps to outline the course of the disease from infancy to old age.

The sub-division into groups is as follows :-

1)	Pre-school age		Birth to 5 years	15 cases
2)	School age	(a)	5 to 10 years	47 "
		(b)	10 to 16 years	21 "
3)	Adult		16 years and older	35 "

School-age Group (a) includes 4 cases also observed in Group 1

School-age Group (b) includes 4 cases also observed in Group 2(a)

ANALYSIS OF CLINICAL FEATURES.

1) NUTRITION.

There is some division of opinion regarding the effect of Patent Ductus Arteriosus on the physical development of the individual. Muir and Brown (1932) found only five out of twenty cases to be below standard development. Gilchrist (1945) found four out of 13 below standard and seven average. Gross (1940), on the other hand, considered retarded physical growth to be sufficiently frequent to warrant surgical attempts at closure of the Ductus, and Gross and Longino (1951) still consider retarded physical development, not attributable to other causes, to be an indication for operation. Shapiro and Keys (1943) found the young adult sufferer to be well-developed physically, but in 1944 Shapiro found on an analysis of 62 cases that only 33 were normal and 23 undersized. Benn (1947) analysed his cases statistically and found that in 17 schoolchildren, the weight was statistically below average but not the height.

It was therefore considered that a statistical analysis of physique, based on a large series such as this which had been observed over several years, would be of value.

Methods of Assessing Physique.

1) Tuxford's Index (Tuxford, 1939) - which is based on the weight-height ratio with an adjustment for age and normally approximates unity, or nowadays possibly a little higher.

2) Comparison of average height and weight with

(a) recognised standards for the same age group, e.g. L.C.C. Schoolchildren (Daley, 1950),

(b) other adequate standards, e.g. Siblings.

It was decided to use the second method in this investigation.

There are no satisfactory standards for children between infancy and school age, and therefore no detailed study was made in this age group. By ordinary clinical standards nutrition appeared to be average in this age group.

Similarly, in adult life there are no satisfactory standards, though comparison with Cruikshank's standards (1946) showed that both male and female adults suffering from Patent Ductus Arteriosus were below average, regarding both height and weight, as in Table III :-

TABLE III

Comparison of Average Heights and Weights of Cases of Patent Ductus Arteriosus with Normal Adults (Cruikshank).

	Height	Weight
Males -		
"Normal" Average	68.5 ins.	140 lbs.
P.D.A. Average	66 "	126 "
Range	62-68 "	102-159 "
Females -		
"Normal" Average	65.5 "	130 "
P.D.A. Average	63 "	119 "
Range	60-68 "	93-146 "

For schoolchildren, however, there are recognised standards based on studies of large numbers of children, the most recent being by Daley (1950).

A preliminary comparison was therefore made, using the average heights and weights of the L.C.C. schoolchildren (Daley, 1950) as standard. Of 61 cases of Patent Ductus Arteriosus, 14 were above average height and 47 below, while eight were above average weight, four average and 49 below.

This obviously merited further investigation of a statistical nature. It is well known, however, that the average size of children varies very much with social conditions, and that different schools in one city may vary considerably one from another, as is shown in the report referred to above. It was therefore decided for statistical analysis not to use the above figures for comparison, but instead to use figures obtained from measurement of the siblings of these cases - as thereby the social status, environment, and heredity factors would be kept as constant as possible.

In the schoolchild (though this does not apply to the younger child) there has been sufficient previous investigation (Menzies, 1940) to assume that the growth curve may be represented by a straight line. For the statistical analysis measurements were used which had been made on 51 cases which were subsequently ligated and followed. These were chosen so that a post-operative comparison might be made (Page 182) but were otherwise unselected, and a

subsequent statistical comparison of these 51 cases with the entire School-age Group as a whole showed no statistical difference, either regarding height or weight, between the 51 cases and the group as a whole. A regression curve was made, based on the last height prior to operation (regardless of age), of the form $H = k + bA$ (H = height in inches, k = constant, A = age in months, b = growth rate in inches per month). This was found to be $H = 31.2885 + 0.1687A$.

A similar curve, based on the heights of 32 siblings, was found to be $H = 32.2594 + 0.1709A$.

Comparison of these two curves (illustrated in Figure II) shows that the average height of these 51 children suffering from Patent Ductus Arteriosus, taken as a group, is statistically significantly below the average height of their siblings at the 5% point ($t = 2.13$) - the odds being 20 to 1 against such a chance occurrence.

Similarly, regression curves were made based on the weights of the 51 children suffering from Patent Ductus Arteriosus and their 32 siblings of the form $W = k + bY + cY^2$, as this is more accurate than a straight line at certain ages (W = weight in lbs., k = constant, Y = age in years). The curve for the 51 pre-operative cases of Patent Ductus Arteriosus was $W = 12.367 + 4.6802Y + 0.0097Y^2$, and for the 32 siblings $W = 22.114 + 4.5276Y - 0.0026Y^2$ (These two curves are illustrated in Figure III).

When these two curves are compared, tests of significance show that the average weight of

FIG. 2 Average height of 51 children suffering from Patent Ductus Arteriosus compared with average height of siblings.

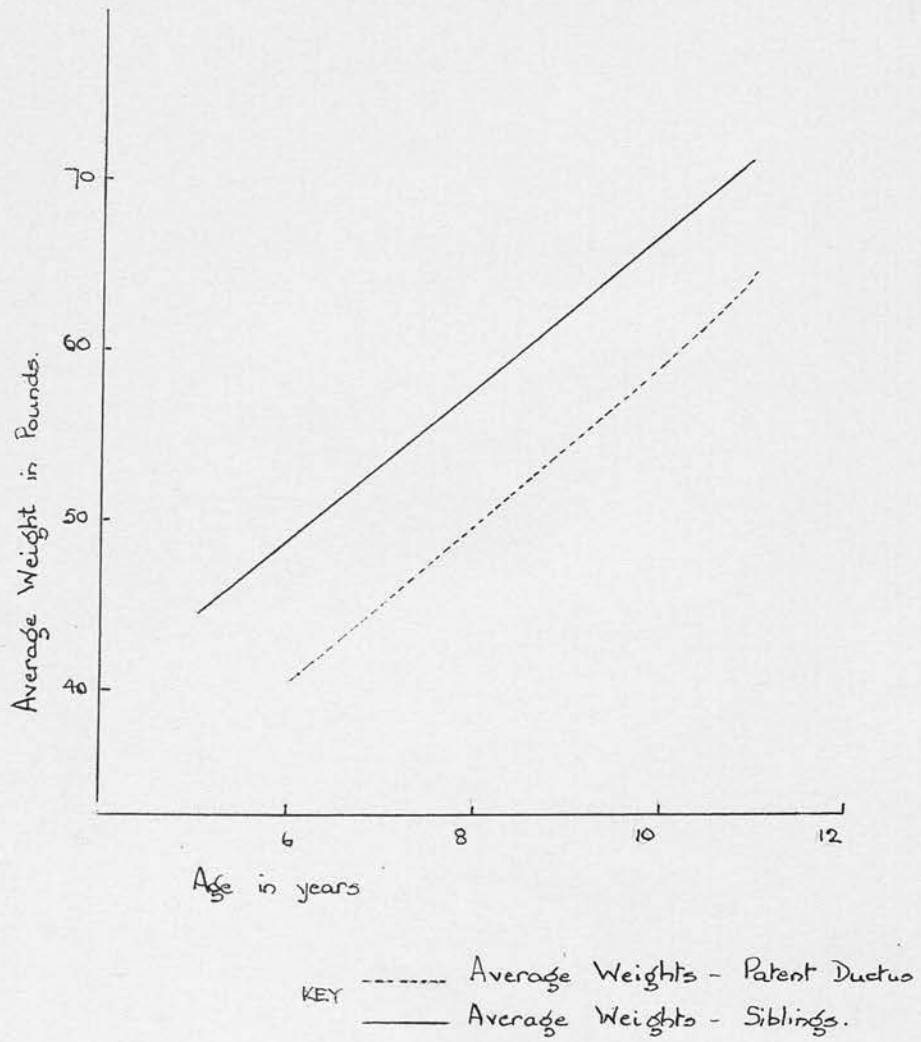


FIG. 3 Average weight of 51 children suffering from Patent Ductus Arteriosus compared with average weight of siblings.

the group of children suffering from Patent Ductus Arteriosus is statistically significantly below that of their siblings. (Since the curves are of the form of a parabola with more than one parameter, there is no t value as when comparing the heights)

SUMMARY.

Statistical evaluation of heights and weights has only been made in the case of schoolchildren, as in the younger child there are no adequate standards for comparison and sufficient studies have not been carried out to establish the form of the growth curves at this age.

In the schoolchild, however, it has been established that the growth curve may be represented by a straight line, or in the case of weight more accurately by a parabola.

It was considered that siblings would make the most satisfactory control group, as thereby the effect of social status, environment, hereditary influence, etc., all of which affect growth, would be minimised being equal in the two groups.

Comparison of the growth curves based on the heights and weights of 51 schoolchildren suffering from Patent Ductus Arteriosus with those based on measurements of 32 siblings shows that both average height and average weight of schoolchildren with Patent Ductus, when taken as a group, are statistically significantly below normal average.

ANALYSIS OF CLINICAL FEATURES (Contd.)

2) CARDIOVASCULAR SYSTEM - PHYSICAL SIGNS

Development of Signs of Congenital Heart Disease.

Of the 110 cases in this series, 35 gave a history that congenital heart disease was recognised before the age of 5 years, thus :-

8 cases were recognised below one year,

4 cases between 1 and 2 years,

12 cases between 2 and 3 years,

7 cases between 3 and 4 years, and

4 cases between 4 and 5 years.

In two cases where children were under the care of their own doctor signs were noted to appear for the first time between the age of 16 and 20 months (case 37), and between 28 and 34 months (case 102).

Unfortunately, detailed physical signs are not known in all the above 35 cases and only 15 were observed by us below 5 years. Using evidence from other sources in addition to our own observations, the following table shows that the percentage showing "typical murmur" increases as 5 years is approached :-

TABLE IV

Incidence of "Typical Murmur" Below the Age of Five Years

Age Group	No. of cases where signs known	No. with typical murmur	% with typical murmur
0-1yr.	3	1	33.3
1-2yrs.	4	2	50
2-3 "	11	9	81.8
3-4 "	7	6	85.7
4-5 "	4	4	100

PHYSICAL SIGNS (Including Blood Pressure Studies).

1) PRE-SCHOOL AGE (Birth to 5 yrs.)

Fifteen children were observed in this age group. Two were a little blue on exercise, but both these cases were complicated by respiratory diseases. In neither case was there any polycythaemia.

Development of Gibson Murmur.

Case 110 was the youngest in which Patent Ductus Arteriosus could be diagnosed with certainty. When first seen at the age of nine months, she already had a systolic thrill and characteristic continuous murmur of moderate intensity and a high Pulse Pressure (B.P. 100/40).

In four cases in this group (the first three of which have been confirmed at operation) the development of the typical murmur was observed -

Case 36 - When first seen aged 1-4/12 years, she had a systolic thrill and a long harsh systolic murmur at the Pulmonary area, followed by an accentuated second sound. From the character of the murmur Patent Ductus was suspected but no diastolic murmur was heard. When next seen, at the age of 5 years, the murmur was quite typical and the Pulse Pressure high (B.P. 105/48).

Case 50 - This child was first seen aged 1-8/12 years. Like Case 36, she had a thrill and a long, harsh systolic murmur at the Pulmonary area which had a reverberant character suggesting a Gibson Murmur, but no diastolic element was heard. Pulse Pressure was raised, Blood Pressure being 92/38.

When next seen, aged 2-5/12 years, a faint hum was heard in the background. Blood Pressure remained much the same, 105/45. No definite diagnosis was reached, Pulmonary Stenosis and Ventricular Septal Defect being considered possibilities. By 3-7/12 years, the murmur was continuous, though the systolic component was more obvious than in most cases, the diastolic being brought out by exercise.

A third child (case 105) was first seen at the age of 2-11/12 years. She had no thrill but a long, characteristic, reverberant systolic murmur at the Pulmonary area, followed by a very much accentuated second sound and a short early diastolic murmur. This latter murmur was continuous with the systolic murmur, but stopped considerably before the end of diastole. Blood Pressure was 110/60. A year later, signs were unchanged. Six months later (aged 4-5/12 years), she had a typical Gibson Murmur of moderate intensity with an accentuated second sound at the Pulmonary area.

The fourth child (case 109), when first seen aged 2½ years, had a loud continuous murmur audible in the supine position, but in the upright position only a very coarse systolic murmur could be made out, although the murmur was so loud that it was transmitted through the bone of the arm to the elbow. Blood Pressure was 90/50. Six months later (aged 3 years), the murmur was quite typical both in upright and supine positions, though unusually coarse for his age.

The other ten children had developed the typical Gibson Murmur when first examined, and during the period in which they were under observation there was little change.

The physical signs present in the 15 cases examined below the age of 5 years are summarised in Table V.

From the foregoing it would appear that signs of congenital heart disease are not usually obvious at birth, and may even be delayed as late as 1½ or 2½ years, but that once the murmur appears it quickly assumes the character of the Gibson Murmur, with a reverberant quality distinct from the more rasping quality of the murmur of Pulmonary Stenosis. In no instance has a case of Patent Ductus Arteriosus been seen below the age of 3 years in which the diagnosis of Patent Ductus has not been entertained even though the diastolic element of the continuous murmur has been missing. In all cases the character of the murmur has been present at the first examination, and this suggests that it develops early. Similarly, from consideration of the four cases in which the murmur has been noted to develop, it would seem that the systolic element appears first and early seems to envelop the second heart sound. Subsequently the diastolic component becomes audible and makes the murmur continuous. One case (109) also demonstrated the fact that in the developing murmur the continuous quality may be detected in the supine position earlier than in the upright.

TABLE V

Physical Signs in 15 Cases Examined Below the Age of Five Years

Case No.	Age in yrs.	Thrill	Murmurs	Blood Pressure	Pulse Pressure	B.P. after exercise
110	¾	Syst.	G.M.(II)	100/40	60	--
	1¼	"	"	110/40	70	
36	1¼	"	P.syst.(III)	--	--	--
50	1¾	?	"	92/38		--
	2½		" + hum			
	3¾	Syst.	G.M.(II)	105/45	60	125/15
107	2½	Nil	G.M.(II)	110/60	50	
	3	"	"	100/50	50	140/55
	3½	"	G.M. (I)	110/55	55	
108	2½	"	G.M.(II)	90/50	40	100/50
	3	"	"	100/50	50	115/30
	3½	"	"	100/50	50	115/30
109	2½	Cont.	G.M(IV)supine	90/50	40	110/50
	3	"	G.M.(IV)	80/40	40	120/20
102	3	Syst.	G.M.(II)M.m.d.	105/50	55	
	3¾	"	G.M.(II)	105/50	55	128/10
	4½	"	"	110/45	65	125/15
105	3	Nil	P.syst.(II) Diast.(I)	110/60	50	
	4	"	do.	110/60	50	135/62
	4½	"	G.M.(II)	110/60	50	130/45
106	3	Syst.	G.M.(II)	110/58	52	130/30
104	3¾	"	" M.m.d.	115/55	60	160/40
	4½	"	"	110/50	60	160/40
103	4	Cont.	G.M.(III)	135/40	95	160/10
	4½	"	"	120/50	70	
56	4½	Syst.	G.M.(II)	108/60	48	130/15
53	4½	Cont.	G.M.(III)	110/58	50	130/30
38	4¾	Syst.	G.M. (I)	105/65	50	110/60
34	4¾	Cont.	G.M.(III)	134/64	70	150/20

Abbreviations -

G.M. = Gibson Murmur
P.syst. = Pulmonary systolic murmur
M.m.d. = Mitral mid-diastolic murmur
I,II,III = Grading of Intensity (Gilchrist)

As regards site of maximum intensity of the murmur, in three of the 15 cases it was heard widely over the precordium. In the others the continuous murmur was localised to the second left interspace close to the sternum, though the systolic and diastolic components could be heard in most cases over the precordium down to the apex.

A thrill accompanied the murmur in the majority of cases (12 out of 15).

It is also apparent that a high pulse pressure develops relatively early in the case with the large Ductus, e.g.,

Case 50 - Blood Pressure aged 1-8/12 years 92/38,
" 110 - " " " 9/12 " 100/40

Exercise Test.

The results are very variable, the main difficulty being apparently in the technique. The children are small: many of them co-operate badly, partly on account of age, partly on account of their reactions to strange surroundings. Of 13 cases which had exercise tests carried out, seven showed a drop in diastolic pressure amounting to 30mm. or more.

2) SCHOOL AGE GROUP (a) 5 to 10 yrs.

47 cases of Patent Ductus Arteriosus were seen between the ages of 5 and 10 years. This included four cases which were also examined in the Pre-school age group (cases 34, 36, 38 and 53).

In this age group all cases, with one exception (case 22), had a fully developed continuous

murmur. Fourteen cases were followed for two years, nine for three years and one for four years. In none did the murmur change significantly. The exception was case 22, who when first seen at the age of 5 years had a slightly enlarged heart, no thrill, and a systolic murmur at the Pulmonary area suggestive of Patent Ductus Arteriosus, followed by a loud second sound but no diastolic murmur. When seen again two years later, the murmur was typical. This case was subsequently confirmed at operation. Another case (93) was a little unusual, in that he frequently had a pulse rate as low as 60 per minute. At this rate, the systolic and diastolic components appeared separate - but when his heart rate increased the murmur was characteristic and continuous. In a third child (48), the murmur was occasionally only systolic when he was resting.

Using Gilchrist's classification of intensity of murmur, it was found that in this group the majority fell into Group II (murmur "churning" or "machinery" in type). The actual numbers in the various groups were as follows :-

TABLE VI

Grading of Murmur Intensity - School Age Group(a)

Intensity of Murmur	No. of cases	Percentage	
Grade I	5	10.6	
" II	26	55.3	85.1
" III	14	29.8	
" IV	2	4.3	
	47		

In all these children the murmur was maximal in the region of the second left interspace close to the Sternum, and apart from different degrees of loudness varied little. Most showed a reverberant murmur with systolic intensification just before the second sound, which was accentuated in all cases, and then a gradual fading of the murmur during diastole. In one case only (98) was the diastolic component louder than the systolic. The murmur was ordinarily well heard in the interscapular region, and in those cases with louder murmurs it was propagated down the left border of the Sternum. In two cases with Grade IV murmurs the murmur was heard widely all over the precordium. In eight cases the Gibson Murmur could be heard faintly at the apex. In seven others a mid-diastolic murmur could be heard which was indistinguishable from that of Mitral Stenosis and quite distinct from the diastolic component of the Ductus Murmur. In all cases where there was a mid-diastolic murmur, the Gibson Murmur was Grade II, III, or IV in intensity, but equally loud Gibson Murmurs were not always associated with a Mitral mid-diastolic murmur.

Associated with the murmur, a thrill could be felt at the Pulmonary area in 41 cases out of 47. In six no thrill could be felt; in four it was faint, but in the remaining 37 the thrill was easily felt. In most cases it was systolic, but in six it was well marked and continuous. In three of the latter cases, the thrill was felt not only at the Pulmonary area,

but widely over the precordium. In these cases the thrill was associated with a murmur of Grade III or IV intensity in a thin child. An additional thrill was felt in one case (100), systolic in time, in the fourth space to the left of the Sternum, and along with other features was considered to be evidence of an associated Ventricular Septal Defect.

Blood Pressure Studies.

These were made under resting conditions in all cases. The average Blood Pressure in the Right Arm was 111/52 - a Pulse Pressure of 59. Judson and Nicholson (1914) found the average Blood Pressure between the ages of 3 and 15 to be 91-106/64-71, i.e. a Pulse Pressure of 30-35. The increase in Pulse Pressure thus appears to be mainly due to the lowered diastolic pressure, the systolic pressure being only a little above average.

In 12 cases the Blood Pressure in the left arm was lower than that in the right. In six of these the difference in systolic pressure between the two arms was 10mm. Hg. or more, and the difference in diastolic pressure 5mm. Hg. or more. These differences all occurred in cases with large Pulse Pressure (55-86), and this difference in pressure between the two arms was considered to be additional evidence of a large shunt. Blood Pressure in the legs was in all cases higher than in the arms.

Exercise Tests.

These were carried out in all but five of the cases in this group, and will be discussed in a

separate section (Page 73).

SCHOOL AGE GROUP (b) 10 to 16 yrs.

21 cases of Patent Ductus Arteriosus were seen between the ages of 10 and 16 years, including four cases which were examined also below the age of 10 years and were included in School Age Group (a).

Two cases were followed for five years, three for two years and the rest for less than one year. The follow-up in individual cases in this group has been less than in the previous group, as once this age group is reached, operation, if to be undertaken, should not be long delayed.

The murmur in all cases was characteristic enough to be diagnostic, though in one case (61) where the pulse rate was slower than average on occasions the diastolic component was unusually pronounced, and in a second case (91) where the murmur appeared to be mainly systolic at rest, exercise or excitement quickly brought out the continuous quality. Both these slightly unusual cases were confirmed at operation.

In the majority of cases, the murmur fell into groups II and III as regards intensity, the actual numbers being as follows :-

TABLE VII

Grading of Intensity Murmur - School Age Group(b)

Intensity of Murmur	No. of cases	Percentage
Grade I	2	9.5
" II	9	42.85 } 85.7
" III	9	42.85 }
" IV	1	4.8
	21	

Comparison with School Age Group (a) shows that the percentage falling into Groups II and III is 85 in both groups, but that on the whole the murmur is louder in the older group.

As in the younger group, the murmur was maximal in the second left interspace (pulmonary area) and associated in all cases with an accentuated and split second sound. In two cases the murmur could be heard loudly all over the precordium. These were murmurs of Grade III and IV intensity respectively. In six cases a well-marked Mitral mid-diastolic murmur was present, which is a slightly higher proportion than in the younger group.

Well-marked pulsation over the second and third left interspace was seen in four cases in this group, and the apex beat was on the whole more forcible than in Group (a).

A thrill was present in the pulmonary area in all cases but two. In four it was faint; in four it was continuous; in the others systolic only.

Blood Pressure Studies.

In this group, average Blood Pressure in the right arm was 120/55 - a Pulse Pressure of 65. This shows a slight rise in Pulse Pressure compared with the previous group, mainly due to a rise in systolic pressure. In only one case was any difference noted in the Blood Pressure readings in the two arms, and this was less than 10mm. Hg. As in the younger group in all cases the Blood Pressure in the leg was higher than in the arms.

ADULT GROUP

This group of 35 cases in all forms perhaps the most interesting group of the series. It covers a wider range of ages, thus :-

16 to 20 years	8	cases
20 to 30 years	14	"
30 to 40 years	6	"
40 years and over	7	"

The youngest in the group has been arbitrarily chosen at 16 years, and the oldest is 64 years. There is much less uniformity both as regards symptoms and clinical features. No fewer than seven in this group presented with Subacute Bacterial Endarteritis as against two in the previous 75 cases. No fewer than eight have died (only two in the previous 75 cases).

Two cases have been followed for ten years; two for seven years, two for three years, three for two years and the rest up to one year.

Six cases in this group showed cyanosis. In case 75 it was present during the entire period under observation and was proved by Arterial Oxygen Saturation tests to be central in type. This was apparently a case of true "Shunt Reversal". In the other five cases the cyanosis was variable and peripheral in type, and due to congestive heart failure.

Congestive heart failure was seen in seven cases, and one gave a history of failure in a previous pregnancy, making eight cases in all. One case of

congestive heart failure occurred at 23 years (case 83) - where Patent Ductus Arteriosus was complicated by rheumatic heart disease. Another occurred at 29 years (case 12), six months after the onset of uncontrolled Bacterial Endarteritis. The other six cases were all above the age of 40 years. It is of interest to note that of seven cases in all seen above the age of 40 years, six showed signs of congestive failure. This figure may be a little misleading owing to the fact that more patients with failure may seek treatment in hospital. Nevertheless it is obvious that congestive heart failure does not occur with any frequency below 40 years of age, but that thereafter it becomes an increasing menace, though the actual incidence is unknown, since the numbers of symptom-free cases at this age are in doubt.

The murmur was typical in all cases but three.

1) Case 83 - She also suffered from Rheumatic Heart Disease, and was admitted with severe Congestive Heart Failure. When the failure cleared temporarily, a faint distant Gibson Murmur was heard, which rapidly disappeared when the congestive failure recurred. Associated features were Auricular Fibrillation, Blood Pressure of 130/55 (Pulse Pressure 75), with a slight drop in Diastolic Pressure to 45 following mild exercise. The diagnosis was confirmed at Post-mortem examination, when a small Ductus was found to be present.

2) Case 71 showed variable cyanosis following exercise. In failure and with fast fibrillation, the signs shown were a reverberant systolic murmur at the Pulmonary area, associated with a loud split second sound and a blowing diastolic murmur down the left border of the Sternum, and a well-marked mid-diastolic murmur at the Mitral area. With failure relieved and pulse rate slowed, he had a low-pitched continuous murmur maximal in the second left interspace close to the Sternum and below the third rib, associated with a systolic and diastolic reverberant thrill, on the evidence of which one could diagnose Patent Ductus Arteriosus with confidence. The murmur, however, varied somewhat from day to day. The character remained the same, but at times the systolic and diastolic components could be heard separately and the continuous quality only on held expiration. At other times, the murmur appeared to be only systolic. It was also noticed that following exercise the thrill disappeared and the systolic and diastolic murmurs became discontinuous for periods varying from three to twenty minutes.

3) Case 75 - When first seen he had severe congestive heart failure associated with a central cyanosis. The pulse was totally irregular. A systolic murmur was audible at the apex, along with a rumbling mid-diastolic murmur. At the base, a soft systolic murmur was followed by a widely split second sound and a soft blowing diastolic murmur along the left margin of the Sternum. In this case, a

continuous murmur was never heard although he was under close observation for a year before death and cyanosis was persistent. At autopsy, the presence of a Stomal Ductus was found, with shunt apparently from Pulmonary Artery to Aorta (i.e. Shunt Reversal).

These three cases are illustrative of the difficulty which occasionally arises in the adult case of Patent Ductus Arteriosus regarding diagnosis by auscultatory signs alone.

In the other 32 cases the murmur was continuous at all times. Grading as regards intensity was as follows :-

TABLE VIII.

Grading of Murmur Intensity - Adult Group

Intensity of Murmur	No. of cases	Percentage	
Nil	1	2.9	
Grade I	7	20	
" II	16	45.6	77.1
" III	11	31.5	
" IV	0	--	
Total	35		

As in the other groups, a murmur of Grade II intensity was the commonest type, but there was a rather higher proportion of Grade I murmurs than in the younger groups. A Mitral mid-diastolic murmur was heard in only six cases (one of which suffered from Rheumatic heart disease). In two others, the Ductus murmur could be clearly heard at the Mitral area, and it was not possible to distinguish a mid-diastolic murmur. In the majority, the site of maximum

intensity of the murmur was in the second space to the left of the Sternum, but on the whole the murmur was heard more widely than in the younger groups (Gilchrist, 1945). In nine cases it was propagated well out under the clavicle. In six others it was heard widely over the precordium.

An accompanying thrill in the second left interspace was only present in 22 cases, and in two of these it was very faint. It was absent in 13. In three cases with well-marked signs, a thrill was also felt in the suprasternal notch and up into the neck. This slight lessening in the intensity of the signs in the older group is probably mainly due to thickening of the chest wall; to a certain extent it may be due to the greater survival of those with the less well marked signs in childhood; it may also be due to a change in character of the murmur as the patient ages. The pitch of the murmur was noted to be lower in the older cases than in the younger.

Blood Pressure Studies.

These have been carried out as in former groups, and the average Blood Pressure in the right arm found to be 134/58, i.e., Pulse Pressure of 76mm. Hg. In this group, however, the actual range is considerably greater than in the younger cases. In eight cases the reading in the left arm was a little lower than in the right, but only in one case was the difference greater than 10mm. Hg. (case 30). As in the younger groups, the Blood Pressure in the legs was consistently higher than in the arms.

EXERCISE TEST.

Bohn (1938) described a simple exercise test which he considered to be an important aid in the differential diagnosis of Patent Ductus Arteriosus. He recorded the Blood Pressure immediately after exercise, as little as ten "knee-bends being sufficient, and found an immediate, transient drop in diastolic pressure. Other workers, Shapiro and Keys (1943), Benn (1947), have found the characteristic drop in diastolic pressure less easy to elicit, and also have questioned its diagnostic value.

With a view to answering these problems, an exercise test has been carried out on 90 cases in the series. This has been repeated following operation. Control tests have also been done on 25 normal children, on 15 with Venous Hum, on 12 with Acyanotic Congenital Heart Disease (Pulmonary Stenosis, Atrial Septal Defect, Ventricular Septal Defect, Primary Pulmonary Hypertension), on three with Cyanotic Heart Disease with continuous murmur, on two cases of Fallot's Tetralogy following a successful Blalock operation, and on ten others (including Rheumatic Heart Disease, Chorea, unresolved Pneumonia).

Technique of Exercise Test.

In the first 20 cases (including 15 children), the test was carried out as suggested by Bohn, using a minor amount of exercise. The results were not satisfactory as only three of the 15 children showed the characteristic drop in diastolic pressure. The technique was therefore adapted as

follows :-

To enable the readings to be made within half a minute of cessation of exercise (average time in this series for first reading 15-18 secs.), it was essential that the child understood fully what was to be done and that he would co-operate. For this reason, exercise tests in children under 3 years were seldom satisfactory. It was also found that the repetition of the test on several occasions was of value.

The amount of exercise needed to produce slight breathlessness varied considerably from case to case, but this was essential in the carrying out of the test.

For the schoolchild, touching toes 20, 30, or 40 times appeared to be the most satisfactory form of exercise, as the briskness of the exercise could be regulated and a first reading thereafter made quickly.

For the older cases, running up a flight of stairs appeared more satisfactory, as on the whole they disliked bending.

The routine adopted in this series was therefore to make readings immediately after

1) touching toes 20 times,
2) touching toes 30 times,
3) touching toes 40 times.
4) If further exercise was needed, two flights of stairs at a running pace (60 steps).

Done in this way, the test may also be used to estimate the individual's capacity for exercise,

and it has proved that the capacity for exercise and the ease with which the characteristic drop in diastolic pressure is produced run closely parallel. A drop in diastolic pressure of 30mm. was considered a positive test.

Results of Exercise Test - 90 cases of Patent Ductus Arteriosus.

a) Under 5 years - 13 children tested

Below 3 years, none were positive, but it was considered that the technique was not satisfactory in any of the cases.

Between 3 and 4 years - Three were positive, two doubtful, with a fall of 15 and 20mm. respectively, two negative.

Between 4 and 5 years - Four were positive for the first time, two doubtful, with a fall of 10 and 15mm. respectively, one negative.

b) 5 to 15 years - 61 children tested

Of these - 47 were positive and 14 were negative.

47 positive tests.

After touching toes	20 times	30
	30 times	+ 1
	40 times	+ 5
After two flights of stairs		+11
	Total	47 tests

14 negative tests.

Two were repeatedly negative,

Twelve in retrospect may have had inadequate exercise.

c) 16 years and older - 18 cases tested

Of these - 15 were positive and three were negative.

15 positive tests.

After touching toes 20 times	7
After two flights of stairs	7
Total	14 tests

3 negative tests.

Insufficient exercise in all three cases (two pregnant).

There is thus evidence that, given adequate exercise, i.e., sufficient to produce slight breathlessness, there is almost invariably an immediate drop in diastolic pressure of 30mm. or more in cases of Patent Ductus Arteriosus. The drop is transient and within one minute or at most two minutes the diastolic pressure has returned to its resting level.

Exercise Test - Controls.

a) Normal children and young adults - 25 cases

11 showed an immediate rise in diastolic pressure of up to 15mm.

2 showed no change,

12 showed an immediate fall. In nine of these the fall was less than 10mm., the remaining three fell 15, 20 and 25mm. respectively. In each case the return to normal level was less abrupt than in Patent Ductus Arteriosus.

b) Venous Hum - 15 cases

7 showed immediate rise in diastolic pressure up to 10mm.

5 showed no change,

3 showed a fall of less than 10mm., with slow return to normal.

c) Other congenital heart disease - 15 cases.

Ventricular Septal Defect - 5 cases

All showed immediate fall in diastolic pressure. This was less than 10mm. in four cases. In the fifth the fall was 50mm., with slow rise to normal (This case was a high septal defect, possibly involving Aortic Valve).

Pulmonary Stenosis - 4 cases

1 showed immediate rise in diastolic pressure of 5mm.

3 showed a fall of 2, 45 and 60mm. respectively, with rapid return to resting level.

Atrial Septal Defect - 1 case

This showed no change following exercise.

Aortic Stenosis - 1 case

Immediate rise of 10mm. after exercise.

Primary Pulmonary Hypertension - 1 case

This boy showed immediate fall in diastolic pressure of 25mm. after mild exercise, and of 55mm. following severe exercise. In contradistinction to the Ductus cases the diastolic pressure remained low and resting pressure was not regained for eight minutes.

Truncus Arteriosus - 3 cases

Exercise was very mild in all three cases.

2 showed rise of 5mm. in diastolic pressure

1 no change.

d) Fallot's Tetralogy after Blalock's operation - 2 cases.

Both showed fall in diastolic pressure, of 5 and 26mm. respectively.

e) Miscellaneous - 10 cases.

Aortic Regurgitation - initial fall of 25mm. diastolic pressure, with slow return to normal.

Mitral disease - 2 cases - One showed initial rise of 5mm., while the other showed initial fall of 15mm.

Non-cardiac (Chorea, Bronchiectasis, Nephritis)6 cases.

3 showed initial rise of 10mm.

3 showed initial fall of 10mm.

One case (resolved pleurisy) showed initial fall of 40mm., with slow rise to resting pressure(8mins.)

Summary.

To be of value, the Exercise Test must be carried out with careful attention to technique.

Readings must be made immediately after exercise (within half a minute), and at half-minute intervals thereafter. For this it is essential to have co-operation on the part of the patient and the cuff must be worn during the exercise.

Exercise must be adequate - the standard adopted in this investigation has been that which produces slight breathlessness, but the exercise should be pushed further before regarding the test as negative.

A fall in diastolic pressure of at least 30mm. Hg., together with an immediate return to resting pressure is taken as a positive test.

A positive test is the rule in Patent Ductus

Arteriosus. Of 54 cases above the age of 5 years, where the exercise was considered sufficient, only two were not positive.

A positive test is not diagnostic of Patent Ductus Arteriosus. It may occur in the normal, though in such cases the fall in diastolic pressure is rarely greater than 20mm., and it has also been seen in Pulmonary Stenosis with a rapid return to resting level as in Patent Ductus Arteriosus. In Ventricular Septal Defect, Primary Pulmonary Hypertension and Aortic Regurgitation there may be an initial fall in diastolic pressure resembling that seen in Patent Ductus Arteriosus, but the return to resting level is gradual.

Figure 4 illustrates the characteristic drop in diastolic pressure with rapid return to normal, which occurs after exercise in Patent Ductus Arteriosus.

Figure 5 shows the effect of exercise which may be seen in Primary Pulmonary Hypertension with Regurgitation; Aortic Regurgitation and certain cases of Ventricular Septal Defect. There is an initial fall in diastolic Blood Pressure, with slow return to resting levels.

<u>SUMMARY OF PHYSICAL SIGNS (CARDIOVASCULAR SYSTEM), including Auscultatory findings, Blood Pressure Studies, and Exercise Test</u>.

In the pre-school child, the Gibson Murmur may develop early as in Case 110, but in most cases the earliest murmur is systolic, and the diagnosis of Patent Ductus Arteriosus is suggested by the character

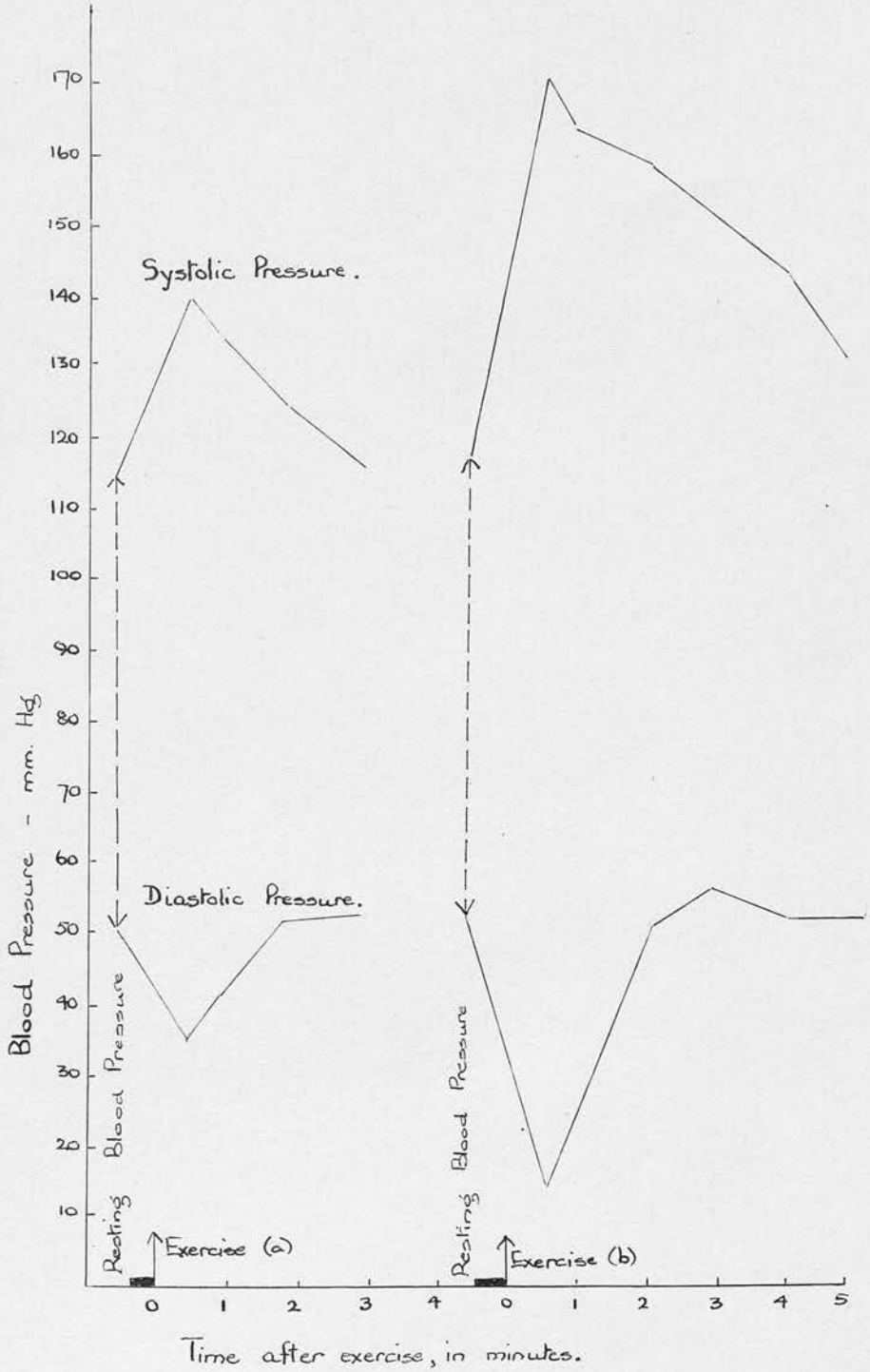


FIG. 4 Characteristic response to exercise in moderately handicapped case of Patent Ductus Arteriosus.
Note: a) Exercise insufficient to produce breathlessness. Fall in diastolic pressure is within normal limits.
b) Exercise sufficient to produce breathlessness. Immediate fall in diastolic pressure, with rapid return to resting levels.

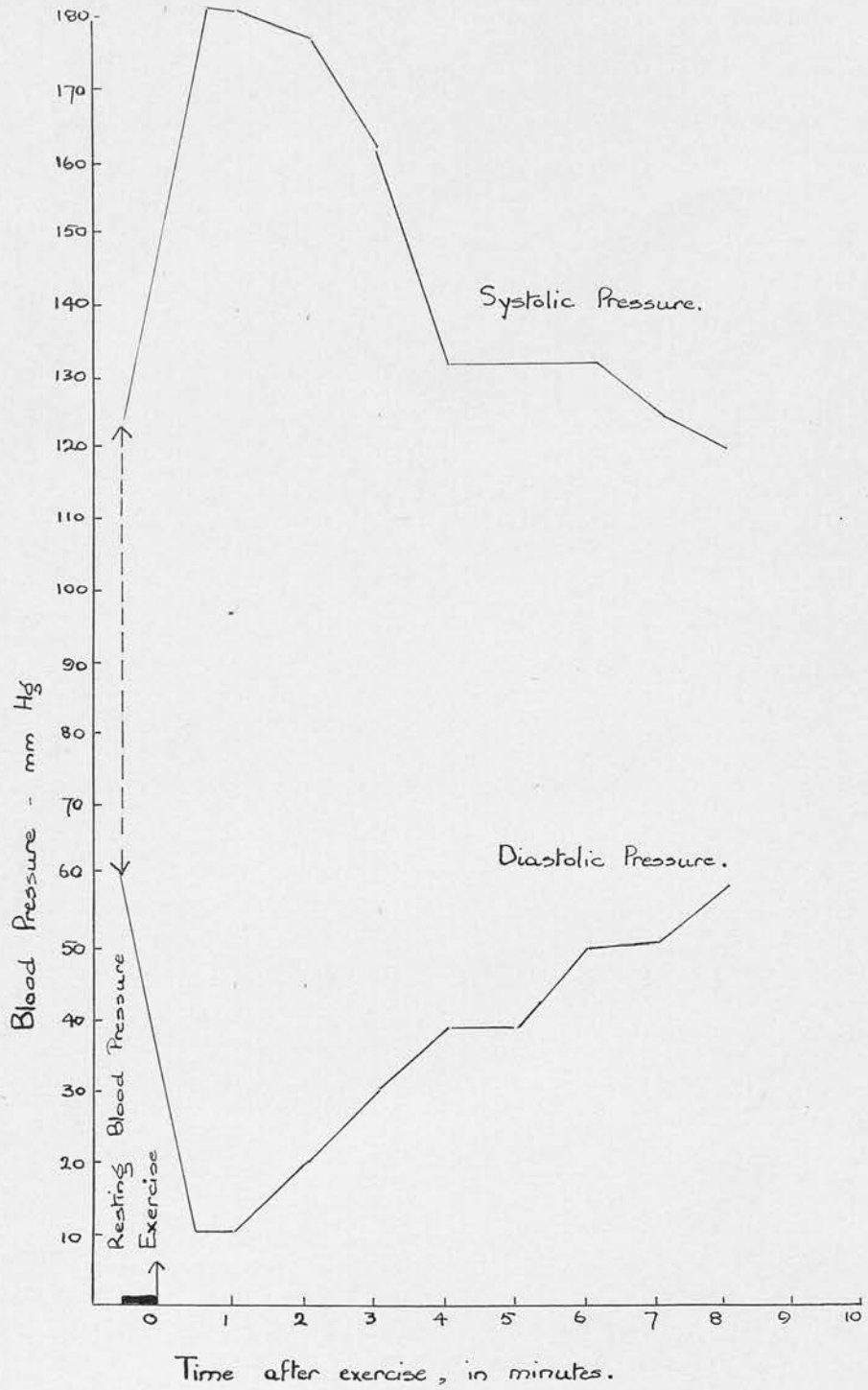


FIG. 5 Exercise Test in case of Primary Pulmonary Hypertension with Pulmonary Regurgitation.

Note: Initial fall in diastolic pressure resembles that seen in Patent Ductus Arteriosus, but return to normal is more gradual.

of the murmur. The reverberant quality of the systolic murmur which appears to run into diastole appears early. Before the Gibson Murmur is fully developed, the continuous quality may be heard by examining the child in the supine position, preferably with no pillow. It is only on rare occasions (two cases in this series) that the murmur is not fully developed by 2½ years of age. An associated feature is a loud and usually split second sound at the base. A systolic thrill, when present, develops early (12 out of 15 cases had it when first examined below 5yrs.) A high Pulse Pressure is another useful pointer to the diagnosis in the young child, as this also develops early, though a normal Pulse Pressure does not exclude Patent Ductus Arteriosus.

The condition is seen in its most classical form in the school child. Of 68 cases in this age group, only five were not characteristic -
In one, the murmur was not fully developed till 7yrs.
In two, the murmur was systolic at rest, but became continuous with excitement or exercise.
In two, with unusually slow pulse rate, the diastolic component was unusually prominent.
The Pulse Pressure gradually increases as the child grows, due to a greater rise in systolic pressure than in diastolic pressure.

In the adult, a much higher proportion show cyanosis and congestive failure (six out of 35 were cyanotic - one with central cyanosis; eight out of 35 had congestive failure). Of seven cases seen

above the age of 40 years, six showed congestive heart failure in some degree.

Difficulty in diagnosis occurred in three cases in this age group owing to absence of continuous murmur in congestive heart failure and shunt reversal.

A detailed Summary of the auscultatory findings and Blood Pressure Studies is shown in Tables IX and X :-

TABLE IX

Physical Signs in Age Groups

Age Group	No.	Thrill	Murmur		Intensity of Murmur			
			Atypical	Absent	I	II	III	IV
0-5	15	12	4	0	13.3 %	53.3 %	26.7 %	6.7 %
5-10	47	41	3	0	10.6	55.3	29.8	4.3
10-16	21	19	2	0	9.5	42.85	42.85	4.8
16+	35	22	-	3	20	45.6	31.5	0

TABLE X

Average Blood Pressure in Age Groups

Age Group	No.	Average Blood Pressure Readings				
		Syst.P.	Diast.P.	Pulse P.	Rt. Arm \ Lt. Arm	Leg \ Arm
0-5	15	107	54	53	-	All
5-10	47	111	52	59	6	"
10-16	21	120	55	65	0	"
16+	35	134	58	76	1	"

With rigorous attention to technique, the Exercise Test described by Bohn may be of considerable

value. Blood Pressure readings must be made within a half-minute of exercise, and thereafter until the diastolic pressure regains its resting level. The exercise must be sufficient to produce slight breathlessness. Under these conditions, 52 of 54 cases of Patent Ductus Arteriosus showed positive tests, denoted by immediate fall in diastolic pressure of 30mm. Hg. or more, and by equally rapid return to resting level. The test is applicable to any age, but since it demands a fair amount of co-operation on the part of the patient it is seldom of value below 3 years of age.

ANALYSIS OF CLINICAL FEATURES (Contd.)

3) RADIOLOGICAL FEATURES.

For the purpose of analysis of the radiological features of Patent Ductus Arteriosus, the X-ray appearances have been studied under the following headings :-

Size of the heart and site of enlargement where present

State of the great vessels

State of the lung fields, including hilar vessels

Size of the left atrium.

In addition, screen examination has been carried out to check the X-ray film appearances, to study the pulsation in the heart and great vessels and to note the presence or absence of hilar pulsation. The method of study thus closely approximates to that of Eppinger and Burwell (1940) and Donovan, Neuhauser and Sosman (1943).

To facilitate comparison of one film with another, the X-rays have been taken as far as possible by the same pair of radiographers, at a constant distance of six feet, with the child or adult in the upright position and with respiration held at ordinary inspiration.

Comparison of heart size in one child with that in another, or comparison of heart size in a child with that in the same child at a later date, immediately introduces difficulties which are not present when making similar comparisons in the adult patient. The taking of standard X-rays itself is

less easy in the child because of growth and there are fewer accepted "normal" standards of measurement for comparison.

In this study, the size of the heart was assessed by an experienced observer (J.P. McG.), but it was felt that for purposes of comparison it would be of value to have measurements in addition, although it was realised that because of the difficulties mentioned above, these observations would not merit statistical evaluation. Cournéau and White (1942) discuss three standard methods of estimating heart size, by utilising

1) transverse diameter of the heart,
2) frontal cardiac area,
3) cardiac volume

They consider that of these, the transverse diameter is the simplest and the least subject to technical errors, being entirely objective, and that it is best used by comparison with predicted "normals", e.g., those provided in the tables of Ungerleider and Clark (1939), who found that 80% of normal cases fell within ±10% of their predicted "normals". The earlier prediction tables of Hodges and Eyster (1926) are less satisfactory, being based on orthodiagraphic tracings and not teleradiograms. Unfortunately, however, neither of these tables are applicable to children. The alternative Cardiothoracic Ratio may be used, the difficulty being to decide the upper limit of normal in the different age groups, since there is no direct relationship between the transverse diameter of the

heart (T.D.H.) and the internal diameter of the chest at the level of the apex (T.D.C.). Danzer, quoted by Eyster (1928), considers the Cardiothoracic Ratio (T.D.H./T.D.C. x 100) normally varies from 39 to 50, and considers figures over 50 indicate probable hypertrophy and over 53 definite hypertrophy. Hodges (1939) also considers measurements above 50 as significant of cardiac enlargement. Cormeau and White (1942) give 50 as the usually accepted upper limit of normal, but themselves regard 55 as more reliable. Benn (1947) has taken as his standards 45 in adults and 52 in children. There are thus serious disadvantages to the use of the Transverse Diameter in the child as a measure of heart size; nor does it take into account enlargement of the left upper border of the heart. On the whole, in Patent Ductus Arteriosus, it is therefore likely to underestimate size.

Cardiac area, based on measurements of long and broad diameters compared with "normals" predicted from measurements of height and weight, may also be used. Ungerleider and Gubner (1942) have published such a Nomogram based on observations made on a large series of cases, but these are not applicable to children. Meyer (1949a,b) has, however, described a simplified method, using similar equations to Ungerleider and Gubner, but covering a wider range of heart size and age. He gives two Nomograms, (1) for 17 years and older, (2) for age 3 to 16 years. Table XI shows a comparison of heart size in ten adult

cases of Patent Ductus Arteriosus, using the nomogram of 1) Meyer and 2) Ungerleider and Gubner. In no case was there a difference of more than 8% - and since Meyer's method was applicable to both children and adults, it was decided to use his method to estimate cardiac area in all cases.

TABLE XI

Cardiac Size - Frontal Cardiac Area

Comparison of results using Nomogram of a) Ungerleider and Gubner b) Meyer

Case	Cardiac area expressed as % above or below predicted normal		Difference
	Ungerleider & Gubner	Meyer	
1.	+19	+22	+3
2.	+26	+23	-3
3.	+22	+19	-3
4.	+36	+30	-6
5.	+5	+0	-5
6.	+22	+14	-8
7.	+19	+15	-4
8.	+50	+45	-5
9.	-11	-12	-1
10.	+34	+25	-9

In no case is the difference greater than 8%. On the whole, cardiac area as estimated by Meyer's method is less than when estimated by the method of Ungerleider and Gubner.

As a measure of cardiac size in this series, a naked-eye assessment has been made with in addition a measurement of the Cardiothoracic Ratio and of the cardiac area as compared with predicted normal, based on Meyer's method.

As in previous sections, the series has been divided into four groups :-

1) Pre-school child — up to 5 years
2) School child — (a) 5yrs. to 10yrs.
3) — (b) 10yrs. to 16yrs.
4) Adult group — 16 years and older,

before being finally considered as a whole. Since the case of Patent Ductus Arteriosus is seen in its most characteristic form in the schoolchild, this group has been considered first.

SCHOOL AGE GROUP (a) 5 to 10 years (47 cases)

Cardiac Size.

Naked-eye assessment revealed that 33 of the 47 cases showed slight to moderate cardiac enlargement, and one case in addition (an infected Ductus) showed gross enlargement, making a total of 34 enlarged out of 47 cases (72%). In most cases, the enlargement was a generalised one, but 13 showed predominantly Left Ventricular enlargement and seven showed a degree of Right Ventricular enlargement which was noteworthy. In seven, there was cardiac displacement to the left, four with associated scoliosis; in one the displacement was to the right.

Measurements of cardiac area (based on Meyer's method) were possible on 46, and showed 34 of the 46 (74%) to be above normal (i.e. more than 10% above predicted "normal"), with an average cardiac area of +20%. Table XII shows the distribution of cases according to cardiac area.

TABLE XII

Cardiac Size - Frontal Cardiac Area - School group(a)

	Cardiac Area - % above or below "normal"								
	-10 to -1	0	+1 to +10	+11 to +20	+21 to +30	+31 to +40	+41 to +50	+51 to +60	+61 to +70
No.of cases in each group	3	2	7	20	8	2	3	0	1
% in each group	6.5	4.4	15.2	43.5	17.4	4.3	6.5	0	2.2

Cardiac size, however, as estimated by measurement of Cardiothoracic Ratio shows only 27 cases to have a Ratio above 50 (i.e. 58.7%). This method does not take account of enlargement of the left upper border of the heart. Table XIII gives detail of the distribution of cases according to Cardiothoracic Ratio :-

TABLE XIII

Cardiac Size - Cardiothoracic Ratio - School group(a)

	Cardiothoracic Ratio (T.D.H/T.D.C. x 100)			
	45.1-50	50.1-55	55.1-60	60.1-65
No.of cases in each group	19	15	8	4
% in each group	41.3	32.6	17.4	8.7

Comparison of the three methods of assessing heart size is shown in Table XIV, and shows how closely the naked-eye assessment parallels assessment by measurement of Cardiac Area. Since it takes into account enlargement of the left upper border of the heart, it is probably a more accurate measurement of heart size in Patent Ductus Arteriosus than is the transverse diameter.

TABLE XIV

Cardiac Size - Comparison of three methods of estimation - School group (a)

	Total No. of cases	No. above normal	% above normal
"Naked Eye"	47	34	72
Cardiac Area	46	34	74
Cardiothoracic Ratio	46	27	58.7

Ten of these cases were followed for periods of two years or over, and in no case was there any significant increase in the size of the heart during the period under observation. In eight there was no increase at all, including Case 22 who was observed over a period of five years, from 5 to 10 years (Fig. 11); in two the increase was by +4%. Similarly, nine other cases followed from one to two years showed no significant increase.

Great Vessels.

Enlargement of the Pulmonary Artery was a very constant feature and was shown in some degree by all 47 cases. In six it only amounted to slight enlargement and these cases were all associated with a heart within normal limits regarding size or only slightly enlarged. In one case (39) the enlargement was very marked, due to the development of a Pulmonary Artery Aneurysm associated with an infected Ductus (Fig. 71).

In a few cases the Aortic knob was not distinguishable but no abnormality was noted in the Aortic Arch which arched to the left in all cases.

Hilar Vessels and Lung Fields.

The hilar vessels were enlarged in all but three cases (7, 22, 28), but expansile pulsation was only seen in four. In two, it was well marked (Cases 46 and 55). It was thus an unusual finding.

The interpretation of the state of the lung fields is open to considerable individual variation, but only six cases in this group appeared to show no increase in vascularity. The degree of vascularity varied considerably - from a degree within normal limits, but which nevertheless became less after operation, to a very marked increase as in Cases 46, 55 and 58 (Figs.59 and 64). In all three latter cases there was clinical evidence of a large shunt.

Two cases showed evidence of pulmonary collapse. In Case 36, this was persistent with displacement of the heart to the left (Fig.37). In Case 94, the collapse cleared and recurred at intervals.

Left Atrium.

In estimating the size of the left atrium, screen examination was found to be extremely valuable as many cases, which appeared to show some increase on the film, were not confirmed when screened. Seven showed definite enlargement, 12 slight, five were doubtful, and three showed displacement backwards of the oesophagus as part of a generalised cardiac enlargement. An enlarged left atrium was usually associated with a large heart and a large shunt as shown in the following table, but not always so, as

Case 39, who had an enormous heart and shunt (Cardiac Area +66%. Cardiothoracic Ratio 61.2, B.P. 105/20), yet had a normal-sized left atrium.

TABLE XV

Size of heart and B.P. in cases showing Left Atrial enlargement - School group (a)

Case No.	Cardiac Area	Cardiothoracic Ratio	B.P.	Pulse Pressure
36	+45	60	112/40	72
46	+70	57.5	120/45	70
51	+20	48.5	130/50	80
55	+30	56.6	120/50	70
58	+40	60.6	126/40	86
66	+45	54.7	115/40	75
101	-6	51.3	100/60	40

Screen Examination.

41 cases showed increased pulsation in Left Ventricle and the great vessels, particularly the Pulmonary Artery. This was a very brisk, active type of pulsation with no time lag between that over Left Ventricle and that in Pulmonary Artery. Two showed slight increase only. In four, pulsation was within normal limits. In three of these latter cases, the heart was only slightly enlarged, while the fourth had an unusually slow pulse, which may have accounted for the unusual screen appearance.

SCHOOL AGE GROUP (b) 10 to 16 years (21 cases)

Cardiac Size.

Assessment of heart size was again done by "naked-eye" assessment, comparison of Cardiac Area

with predicted "normal" and estimation of Cardiothoracic Ratio. As before, the numbers estimated as enlarged by the first two methods were similar (67%). The average cardiac area was +20.3% above predicted normal. Tables XVI and XVII show distribution of cardiac size in the group as estimated (a) by cardiac area, (b) by cardiothoracic ratio. Table XVIII compares the three methods of estimation.

TABLE XVI

Cardiac Size - Frontal Cardiac Area - School group(b)

	Cardiac Area - % above or below "normal"							
	-10 to -1	0	+1 to +10	+11 to +20	+21 to +30	+31 to +40	+41 to +50	+51 to +60
No. of cases in each group	2	1	4	6	3	2	1	2
% in each group	9.5	4.8	19	28.6	14.3	9.5	4.8	9.5

TABLE XVII

Cardiac Size - Cardiothoracic Index - School group(b)

	Cardiothoracic Index (T.D.H/T.D.C. x 100)				
	35.1-40	40.1-45	45.1-50	50.1-55	55.1-60
No. of cases in each group	1	1	10	6	3
% in each group	4.8	4.8	47.6	27.5	14.3

TABLE XVIII

Cardiac Size - Comparison of three methods of estimation - School group (b)

	Total No. of cases	No. above normal	% above normal
"Naked Eye"	21	14	67%
Cardiac Area	21	14	67%
Cardiothoracic Index	21	9	43%

The average cardiac area in this group is thus only a little greater than in the younger group (+20.3% as compared with +20%). This suggests that in the average case there is little increase in the size of the heart during school years, a conclusion already reached by the follow-up of cases in the younger group and corroborated by three cases in this group followed over two years, who showed no increase in heart size during the period under observation.

As in the younger group, the enlargement in most cases was generalised. In five it was mainly due to increase in size of the Left Ventricle, while in two right-sided enlargement was greater than left. The cases showing Left Ventricular enlargement all had large hearts (Cardiac Area +40%, +40%, +19%, +52%, +58%), while the two showing Right Ventricular enlargement were not associated with gross cardiac enlargement (Cardiac Areas +5%, +12%).

Great Vessels.

As before, the Aorta was normal in all cases, while Pulmonary Artery prominence varied from slight to very marked enlargement. The size of the Pulmonary Artery bore some relationship to the size of the estimated shunt as e.g. Case 45 (Fig. 54), who had very gross signs and who was found at operation to have a large Stomal Ductus.

Hilar Vessels and Lung Fields.

All but one case showed increase in the hilar shadows, but only ~~two~~ one (with Stomal Ductus) showed expansile pulsation.

Left Atrium.

Two estimated to have a large shunt (Pulse Pressure of 68 and 70 respectively) showed definite enlargement of Left Atrium, five were slightly enlarged, six were doubtful and not confirmed on screen examination.

Screen Examination.

The brisk, active pulsation seen in the younger group was again present in most cases, but was less universal. No fewer than five of the 21 cases had pulsation within normal limits. Case 45, which proved to have a Stomal Ductus, showed very marked increase in pulsation over Left Ventricle and great vessels, together with hilar dance.

PRE-SCHOOL GROUP (up to 5 years) 15 cases

Having thus described the radiological features of the classical Patent Ductus Arteriosus, we may now turn to the pre-school age group. We have seen that by the time 5 years is reached, cardiac enlargement has already occurred in approximately 70%, and there is little change during school life. Pulmonary Artery enlargement is the most constant finding, being present in all, as is some congestion of the hilar and lung fields. Left Atrial enlargement occurs usually where there is evidence of a large shunt. Active brisk pulsation of Left Ventricle and Pulmonary Artery is seen on screen examination, but is rather less useful a sign in the older school child than it is in the younger.

Cardiac Size.

It was not possible to utilise measurement of cardiac area in all cases in this group, as some were too young, but using the Cardiothoracic Ratio as an index, six of the 15 cases had a Ratio of 55 or over and 13 were 52 or over. Even allowing for the fact that the transverse diameter of the heart in the infant is relatively larger than in the older child, early cardiac enlargement appears to be common. Of four children seen below 2½ years each had a Cardiothoracic Ratio above 55.8 (55.8, 56.6, 58, 59 respectively). Two of these cases who were followed for more than two years showed further cardiac enlargement :-

Case 36 - aged 16 months, Cardiothoracic Ratio 56.6
aged 5 years, it was 57.5 (Fig. 37)

Case 50 - aged 20 months, Cardiothoracic Ratio 55.8
aged 3½ years, it was 58.1 (Fig. 8)

The increase in heart size usually affected both Ventricles, though one case (102) showed more right-sided enlargement and Case 105 well-marked Left Ventricular enlargement (Fig. 9).

Great Vessels.

As with generalised cardiac enlargement, so Pulmonary Artery enlargement occurs early. Some enlargement of Pulmonary Artery was present in all, with increased hilar shadow and increased broncho-vascular markings in the lung fields.

Left Atrium.

This appeared increased in practically all,

but was of doubtful significance at this age, being present in many normal children.

Screen Examination.

This was of particular interest in this group regarding the development of typical increased pulsation.

In three cases, below the age of 2 years, screening was unsatisfactory.

Three were screened between the age of 2 and 3 years, One (Case 108) showed increased pulsation over the left border of the heart, to a lesser extent in the Pulmonary Artery. The other two, though active, were not typical.

Of five, screened between 3 and 4 years, one was unsatisfactory because of crying, two were within normal limits, one showed increased pulsation over the left border (Case 104), and one was typical (Case 105).

Seven were screened between 4 and 5 years, one was within normal limits, one showed increased pulsation over the Left Ventricle only (Case 102), while five were typical.

No case in this age group showed any expansile pulsation of the hilar vessels.

The appearance of brisk pulsation over Left Ventricle and Pulmonary Artery is thus relatively late in developing and few cases below the age of 4 years show it. Screen examination is thus of little extra help in the diagnosis of the doubtful case in the earlier years.

ADULT GROUP (16 years and over)

35 cases were in this group, seven of which were infected and must be considered separately. One was complicated by Rheumatic Mitral disease, leaving 27 uncomplicated cases.

Heart Size.

In the uncomplicated case between the age of 16 and 45 years, the average cardiac area was +20.8% above normal, being thus only a little greater than in the schoolchild. There was, however, a striking difference in the distribution as only three of the 27 cases fell within normal limits, against 25% to 30% in the school age group. As can be seen in Figs. 6 and 7 the scatter in this group is fairly even below 45 years, and there is no direct correlation between age and the size of the heart. Above 45 years, however, there is a marked change, and all five cases seen at this age showed marked cardiac enlargement. Tables XIX and XX show the distribution of cases according to heart size in the adult group (26 cases available for measurement).

In the older cases, Left Ventricular hypertrophy became more marked. Of 12 cases seen above 30 years all but two showed Left Ventricular enlargement to some degree. The two which did not show it (Cases 77 and 82) had unusual features and had more right-sided enlargement than usual. Below 30 years, Left Ventricular enlargement was less obvious. In three, it was part of a generalised cardiac enlargement. In five, it was the most

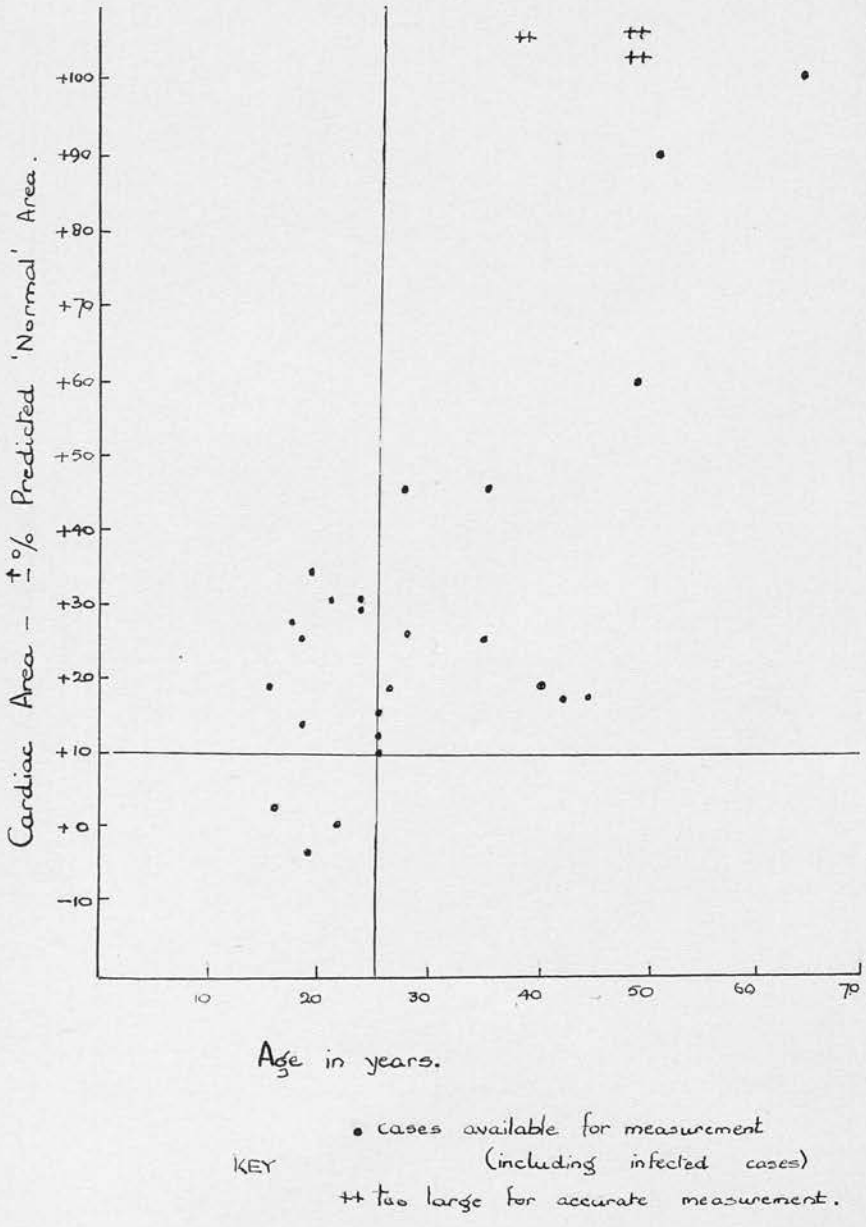


FIG. 6 35 adult cases of Patent Ductus Arteriosus: age in relation to Cardiac Area. None above 25yrs. has Cardiac Area within normal limits. All above 45yrs. have very large hearts (Cardiac Area +50% or more).

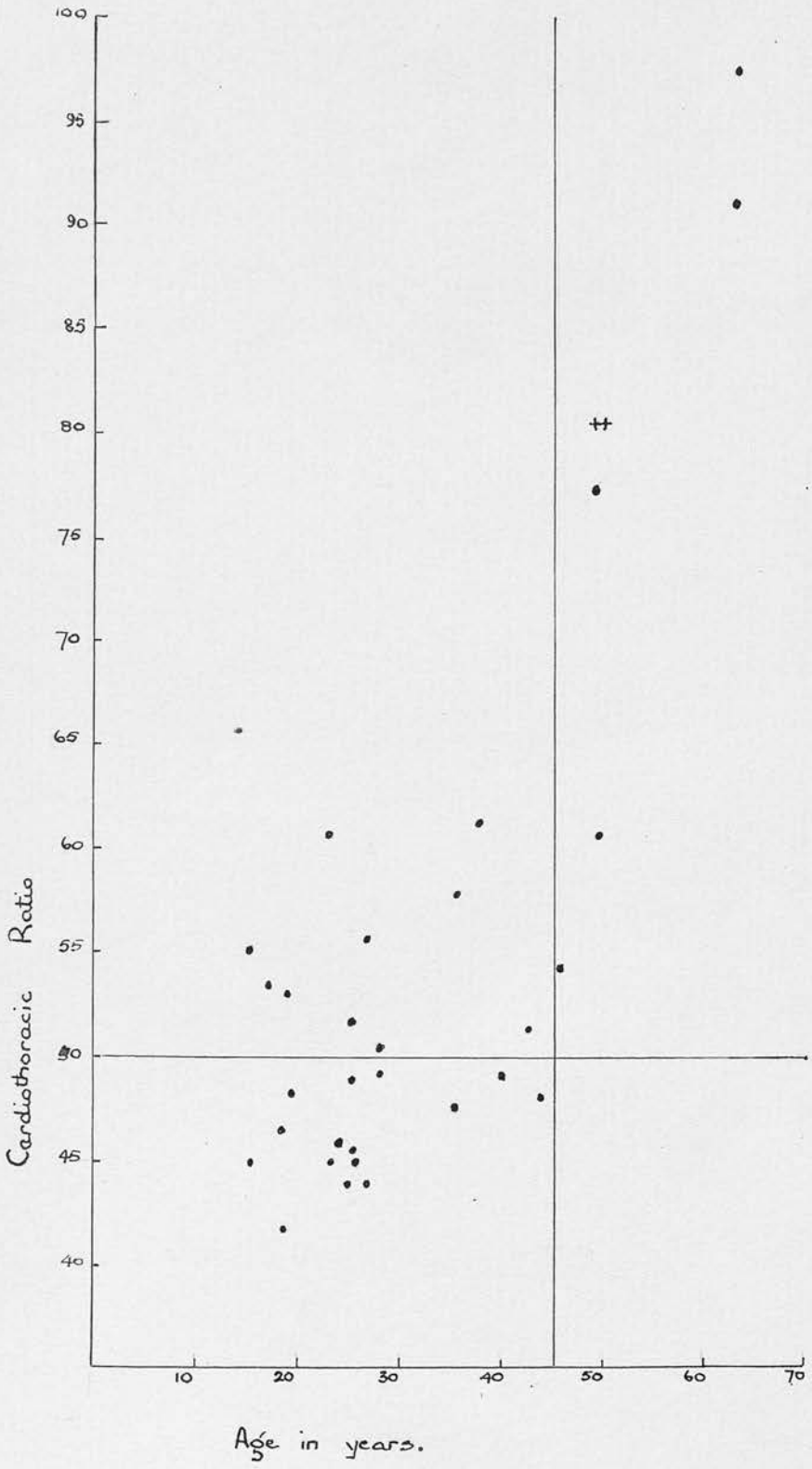


FIG. 7 35 adult cases of Patent Ductus Arteriosus: age in relation to Cardiothoracic Ratio. All above 45yrs. have very large hearts (C.T.R. 53 or over).

Note similar number below 45yrs. with ~~equally~~ high Cardiothoracic Ratio.

TABLE XIX

Cardiac Size - Frontal Cardiac Area - Adult Group

	Cardiac area - % above or below "normal"											
	-10 to -1	0	+1 to +10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100
No. of cases in each group	1	1	1	6	8	1	2	1	0	0	1	1
% in each group	4.35	4.35	4.35	26.0	34.7	4.35	8.7	4.35	0	0	4.35	4.35

In addition three hearts were so large as to be unmeasurable, making a total of 23 out of 26 cases showing increase in cardiac area above normal (88%).

TABLE XX

Cardiac Size - Cardiothoracic Ratio - Adult Group

	Cardiothoracic Ratio (T.D.H/T.D.C. x 100)							
	40.1-45	45.1-50	50.1-55	55.1-60	60.1-65	65.1-70	70.1-75	75+
No. of cases in each group	1	11	6	3	3	0	0	1
% in each group	4%	44%	24%	12%	12%	0	0	4%

In addition one very large heart was not measurable, making a total of 14 out of 26 cases with a cardiothoracic ratio of 50 or over (54%).

marked feature. In two of these latter cases the heart size was within normal limits, although there was well marked increase in size of the Left Ventricle (confirmed pathologically in Case 70, Fig. 48). Seven cases below 30 years showed no Left Ventricular enlargement at all.

Great Vessels.

The Aortic Arch, as in the younger cases, arched to the left in all. Its appearance was difficult to estimate because of the proximity of the somewhat prominent Pulmonary Artery, but in the majority it was rather flat or poorly defined. Calcification was noted low in the Arch in six cases. With the exception of Case 83, all cases showing calcification were 39 years or more. Case 78 is of interest in that the plaque of calcification was noted to develop between the age of 35 and 40 years(Fig.13).

All cases showed some enlargement of the Pulmonary Artery with the exception of Case 80, and all cases over 45 years showed it to a marked degree. In Case 75, it was very marked (aged 47 years) closely resembling the radiological picture of atrial septal defect. On the whole, there was some relationship between cardiac size and the degree of Pulmonary Artery enlargement, but there were exceptions, e.g.,

Case 77 - Heart size normal limits, marked enlargement of Pulmonary Artery anteriorly (Fig. 15).

Case 70 - Heart size normal limits, Left Ventricular enlargement, moderate enlargement of Pulmonary Artery (Fig. 46)

Case 80 - Generalised cardiac enlargement, no enlargement of Pulmonary Artery.

Hilar Vessels and Lung Fields.

As in children, hilar enlargement and pulmonary congestion followed fairly closely the size of the Pulmonary Artery and the amount of estimated shunt, but there were exceptions where the degree of hilar enlargement and pulmonary congestion were much less than the size of the Pulmonary Artery would have suggested, as in Cases 42 and 77.

Left Atrium.

Twelve cases in this group showed definite left atrial enlargement. In one (Case 83) it was very gross (Fig. 49), but as this case was complicated by Rheumatic Mitral disease this has been discounted. In six of the remaining 11, it was well marked, and in five it was slight. There was some enlargement of the Left Atrium present in all cases with large hearts, though the degree of enlargement of Left Atrium bore no relationship to the size of the heart.

Screen Examination.

Hilar dance was again a rare finding, expansile pulsation of the branches of the Pulmonary Artery being seen in only four cases (72, 75, 79, 87). The brisk pulsation so characteristically seen in the school child was less conspicuous in this group - only being seen in its typical form in 13 cases and to a lesser extent in two others of 24 cases screened in this group. Two were inconclusive because of tachycardia and pregnancy. The remaining seven were

definitely unusual. Two showed no increase in pulsation whatever. In three, increased pulsation was confined to the Pulmonary Artery, while the remaining two showed increased pulsation mainly in the Aorta. Thus screen examination is frequently of little additional help in the older case with atypical physical signs.

Infected Cases.

Seven cases between the ages of 16 and 32 years were admitted with bacterial endarteritis. X-ray of these cases was in every way typical of Patent Ductus Arteriosus, but the heart size was considerably greater than in non-infected cases of the same age. They all showed general cardiac enlargement with the exception of Case 25, and had an average Cardiac Area of +23.2%, and an average Cardiothoracic Ratio of 54.1. The Pulmonary Artery was enlarged in all. The lung fields showed evidence of infarction in four cases, and signs of congestive heart failure in two.

SUMMARY.

Cardiac Size.

Slight to moderate cardiac enlargement is present in at least 60% of cases of Patent Ductus Arteriosus, and develops early. Four cases seen below the age of 2½ years all had a Cardiothoracic Ratio of 56 or more with further increase up to 5 years. At this early stage enlargement usually affects both ventricles equally.

In the younger school child (5 to 10 years), 34 of 46 cases (74%) showed cardiac enlargement with an average Cardiac Area of +20% above predicted "normal" for height and weight. This enlargement was mainly generalised, but the Left Ventricle was prominent in 13 (27.6%), and the Right Ventricle in seven (14.9%).

In the older school group, generalised cardiac enlargement was present in 14 cases out of 21 (67%), with an average cardiac area of +20.3%. In five (23.8%) the enlargement was mainly due to the Left Ventricle. In two (9.5%) the Right Ventricle was prominent.

In the adult group, the position was changed. Of the non-infected cases, 23 (88%) had a cardiac area above normal, though below 45 years the actual increase in area compared with the school child was slight (+20.8%). Of seven infected cases between the ages of 16 and 32 years only one was within normal limits regarding size, and the average cardiac area was a little higher than the average for the group (23.2% against 20.8%). Above 45 years, however, all five cases seen had very large hearts (cardiac areas of +100%, +90%, +60%, and two unmeasurable). In the adult, particularly above 30 years, Left Ventricular enlargement was much more conspicuous than in the child. Of 12 cases over 30 years, all but two showed Left Ventricular enlargement to some degree.

Cardiac enlargement thus appears early and there is little change throughout school life and

early adult life. This is borne out both by the follow-up of individuals and by comparison of average cardiac area in the different age groups. The enlargement is originally mainly generalised, but Left Ventricular enlargement becomes increasingly prominent in adult life. It would seem that the marked cardiac enlargement seen in the older cases develops rapidly in later years rather than by slow increase throughout adult life.

Great Vessels.

Pulmonary Artery enlargement is the most constant of all signs and also appears early, being seen in all 110 cases, including those under 5 years, with the exception of one adult. This enlargement persists, varying considerably from case to case, and bearing some relationship to the amount of shunt. All cases above 45 years showed it to a marked degree.

In the majority, the Aorta appeared rather flat and poorly defined, arching to the left in all cases. The main interest in the Aorta was the development of calcification low in the arch in later life. Its presence may be of value in the doubtful case.

Hilar Vessels and Lung Fields.

Increased hilar shadows and pulmonary congestion are also seen in most cases from an early age, though hilar dance was an infrequent finding - nil below 5 years, four of 47 in the younger school group, two of 21 in the older school group, and four of 28 adults.

Left Atrium.

Left Atrial enlargement is common below the age of 5 years, but of doubtful significance at this age. Of 47 schoolchildren below 10 years, it was present in seven and slight in 12. Of 21 school children above 10 years it was present in two and slight in five. Of 27 uncomplicated adult cases it was present in seven and to a slight extent in five. On the whole, its presence is corroborative evidence of a large shunt.

Screen Examination.

This did not prove helpful in the diagnosis of the doubtful case in the pre-school group. At this age, excitement may closely mimic the brisk pulsation characteristic of the Patent Ductus, and below the age of 4 years only one of eight cases examined was typical. In the school child, brisk pulsation was seen best in the younger group. In five of the 21 in the older group, pulsation was within normal limits, although other signs were definite. Of 24 uncomplicated adults screened, only 13 showed the pulsation over Left Ventricle and Pulmonary Artery in its typical form, five were atypical, with increased pulsation mainly in one or other of the great vessels, while two were within normal limits. Of the seven infected cases, four were fit to be screened, and all four showed brisk pulsation over Left Ventricle and Pulmonary Artery.

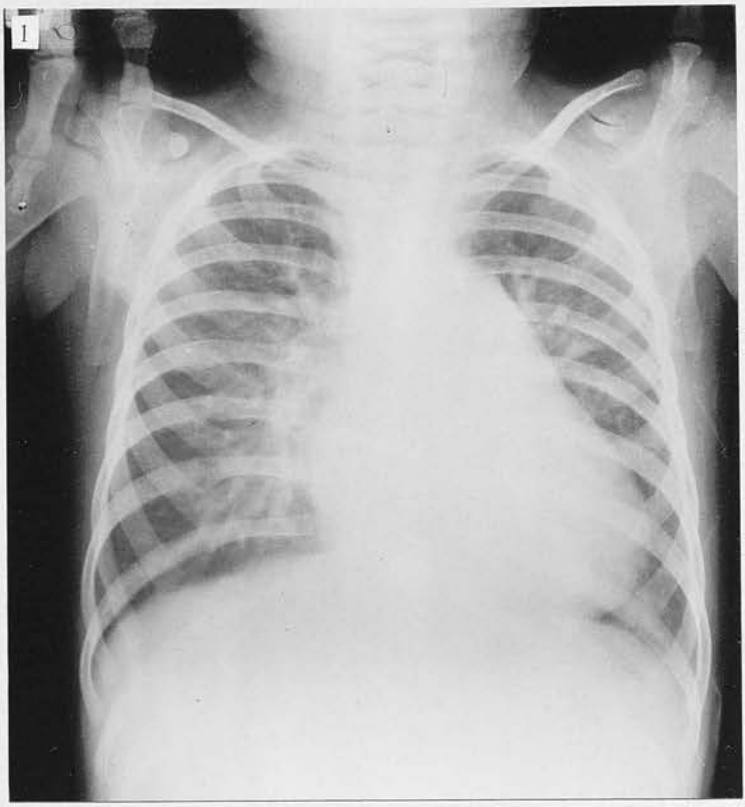
The Radiological Features of Patent Ductus Arteriosus are summarised in Table XXI.

TABLE XXI

Radiological Features of Patent Ductus Arteriosus.

Age Group	0 to 5yrs.	5 to 10yrs.	10 to 16yrs.	16yrs. and older	
No. in Group	15	47 (2 infected)	21	35 (7 infected (1 + Rheumatic Heart Disease	
Cardiac Size				Uncomplicated	Infected
Naked Eye Enlargement	86.6%	72%	67%	85.2%	88.8%
Cardiac Area above +10%	--	74%	67%	88.0%	100.0%
C.T.Ratio above 50	55+ 40%	58.7%	43%	54.0%	60.0%
Av. Cardiac Area	--	+20%	+20.3%	+20.8%(16-45yrs) +85% (45yrs)	+23.2%(16-32yrs)
Pulm. Artery Enlargement	100%	100%	100%	97.1%	
Left Aortic Arch	100%	100%	100%	100%	
Calcification in Aorta	0	0	0	17.1%	
Hilar Vessels enlarged	100%	93.6%	100%	97.1%	
Lung fields congested	100%	87.2%	100%	88.5%	
Hilar dance	0	8.5%	9.5%	14.3%	
Left Atrial enlargement	--				
definite		14.9)40.4%	9.5)33.3%	25)40.6%	
slight		25.5)	23.8)	15.6)	
Typical pulsation on screen examination	aet.2 0/3cases " 3 1/5 " " 4 5/7 "	87.2%	76.1%	54.8%	

1)



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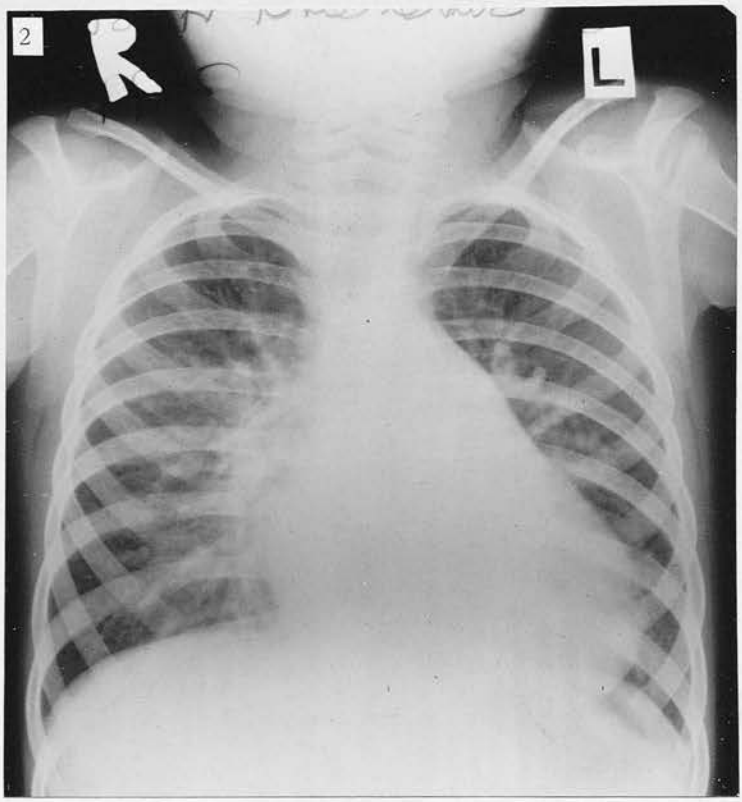
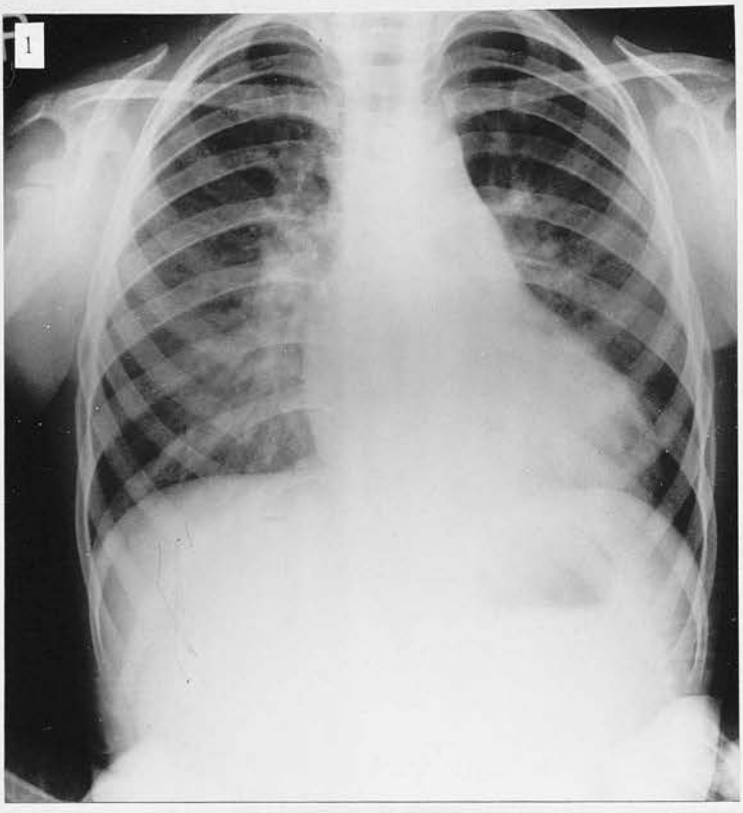


FIG. 8 Radiograph of Case 50. Early cardiac enlargement with further increase in size during pre-school period.

1) P.A. age 1½yrs. C.T.R.55.8
2) P.A. age 3½yrs. C.T.R.58.1
Generalised cardiac enlargement
Prominent Pulmonary Artery
Congested Lung fields.

1)



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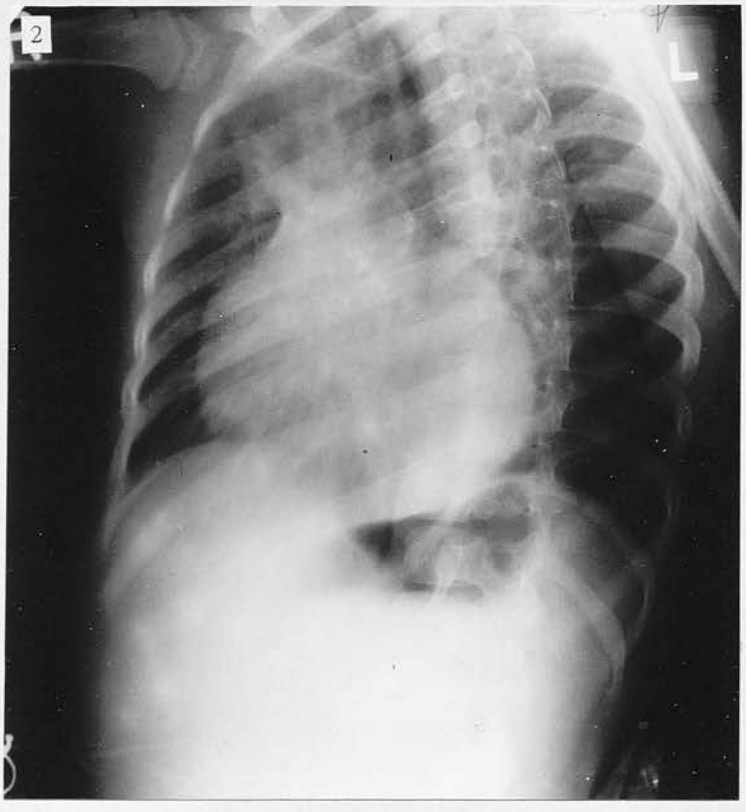
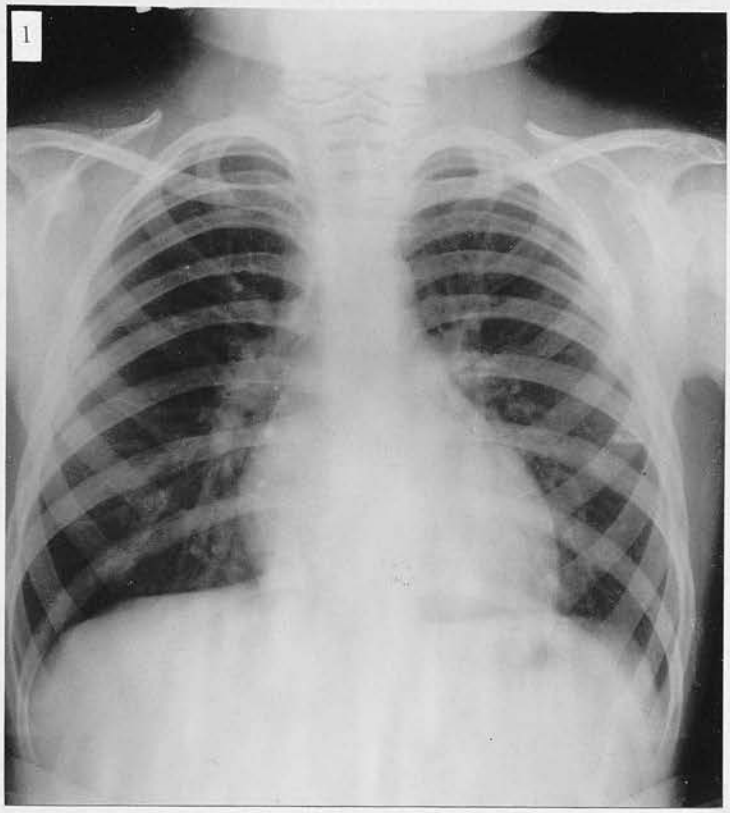


FIG. 9 Radiograph of Case 105. Early cardiac enlargement with unusual degree of L.V. enlargement at 4yrs.

1) P.A. 2) L.A.O. C.A.+20% C.T.R.57.5
Enlargement of Left Ventricle
Slight prominence of Pulmonary Artery
Hilar shadows and lung vascular markings increased.

1)



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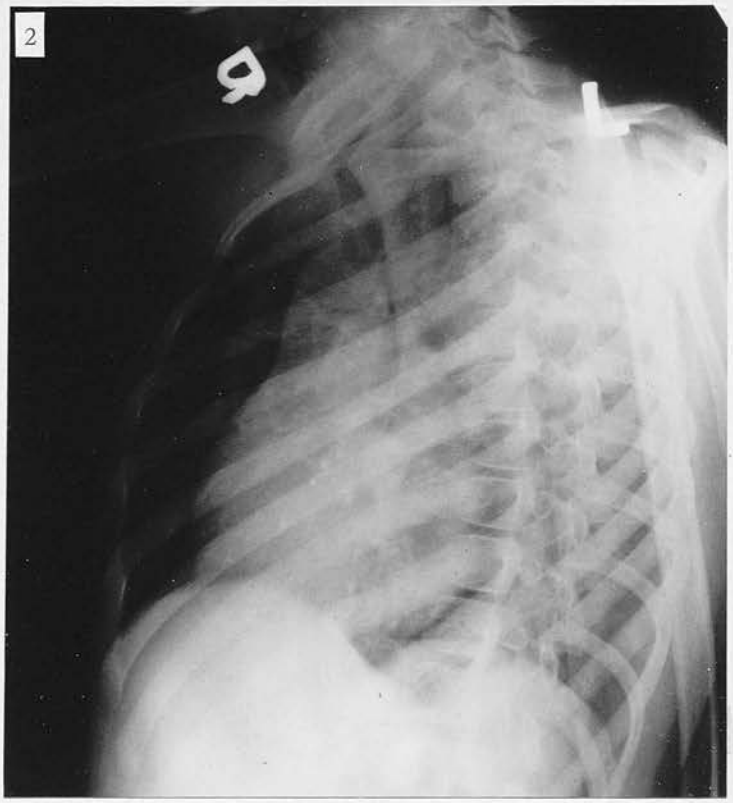
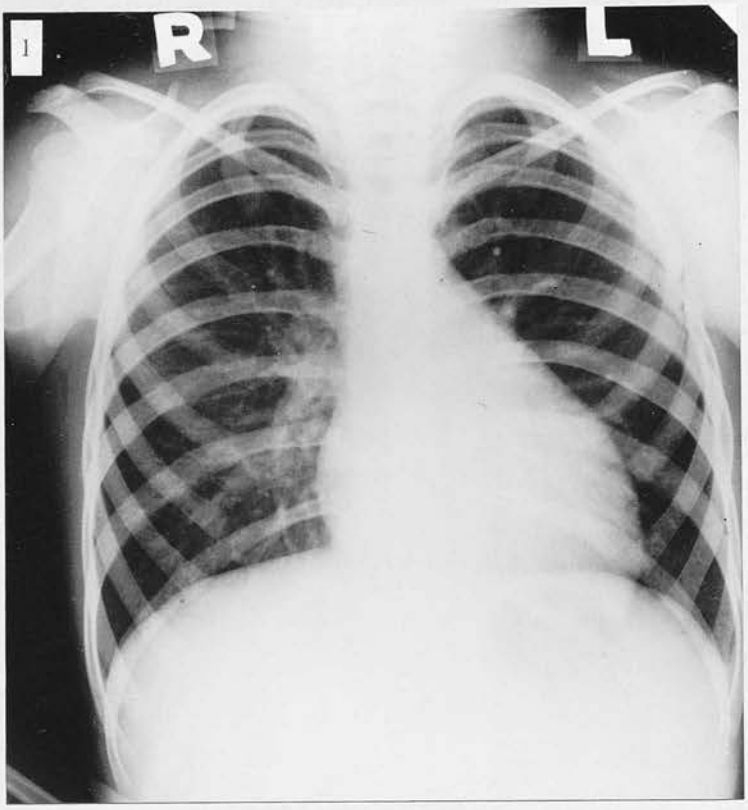


FIG. 10 Radiograph of Case 23. Slight cardiac enlargement with unusual degree of R.V. enlargement in school child.
1) P.A. 2) L.A.O. Age 6yrs. C.A.+8%
C.T.R.48
Slight generalised enlargement particularly of right side.
Slight prominence of Pulmonary Artery
Increase in lung vascular markings

1)



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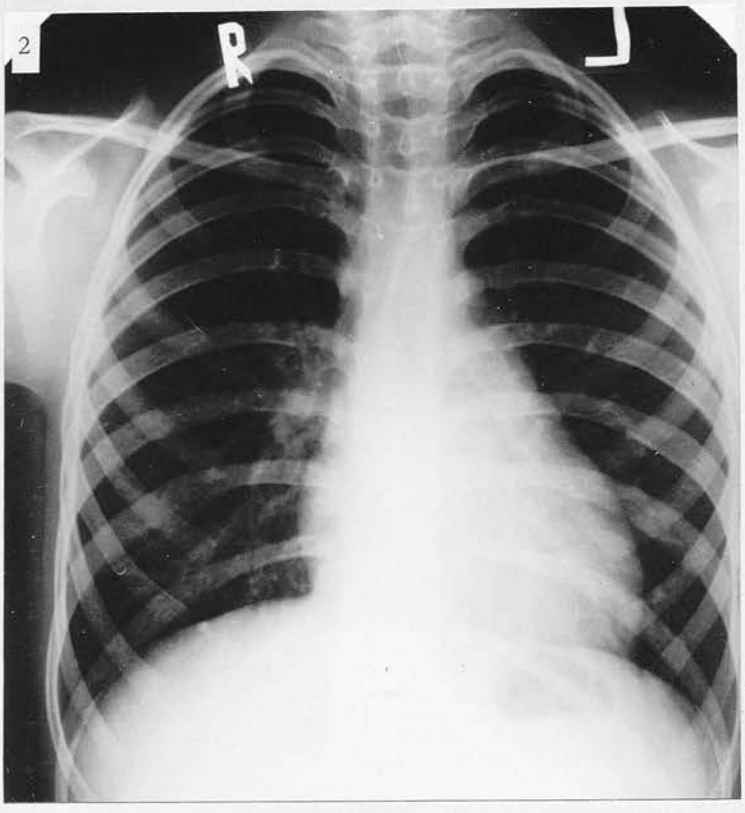
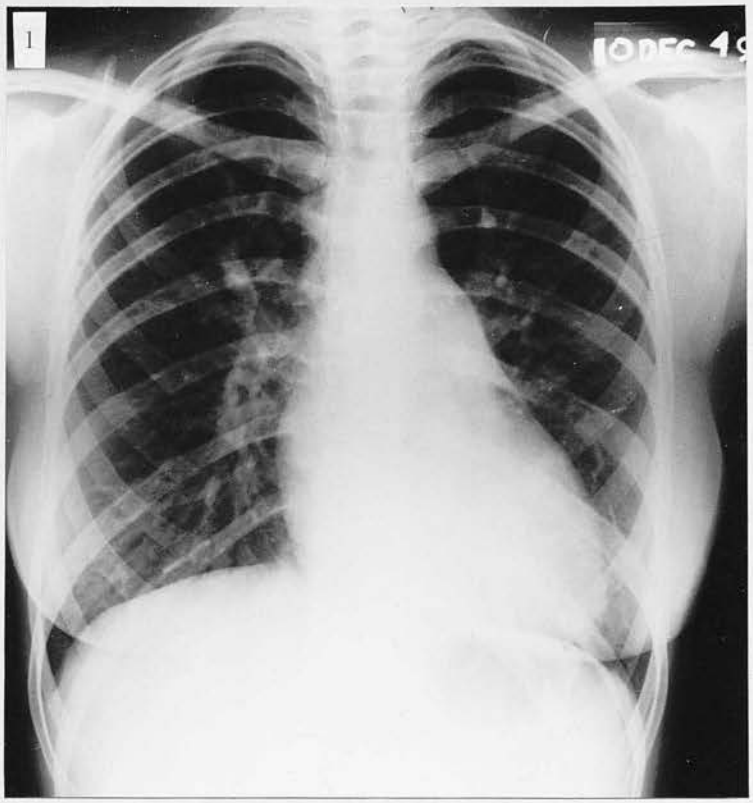


FIG. 11 Radiograph of Case 22. Little change in cardiac size throughout school life.
1) P.A. age 5yrs. - C.T.R.51.2
2) P.A. age 10yrs. - C.T.R. 50.4
Slight generalised cardiac enlargement
Moderate enlargement of Pulmonary Artery
Slight increase in lung vascular markings

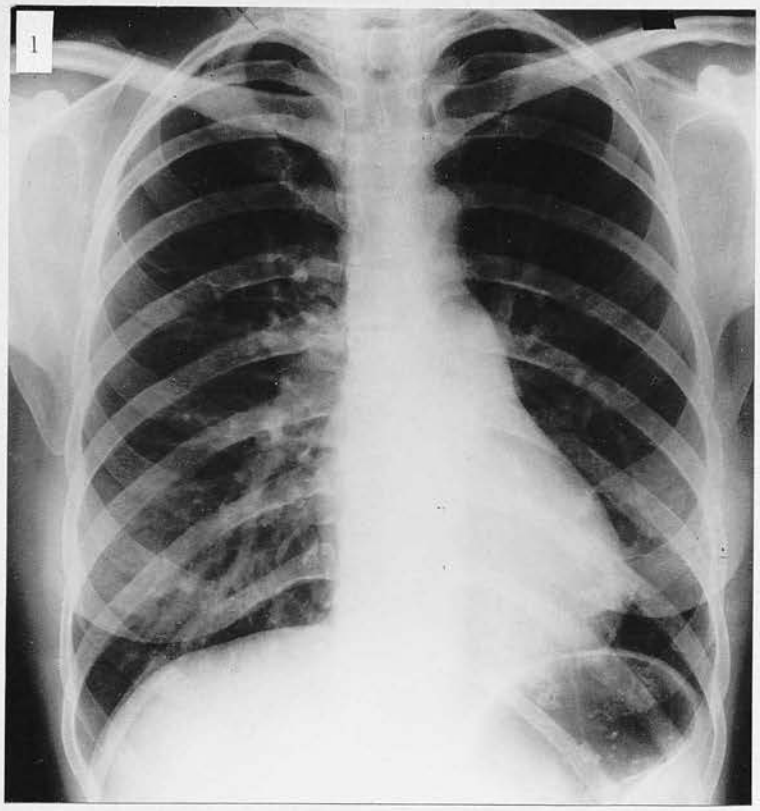
1)



2)

FIG. 12 Radiograph of Case 59. Large Patent Ductus in early adult life.
1) P.A. 2) R.A.O.
Generalised cardiac enlargement, C.A. +28%
C.T.R. 53.6
Prominent Pulmonary Artery
Congestion of hilar vessels and lung fields
Enlargement of Left Atrium.

1)



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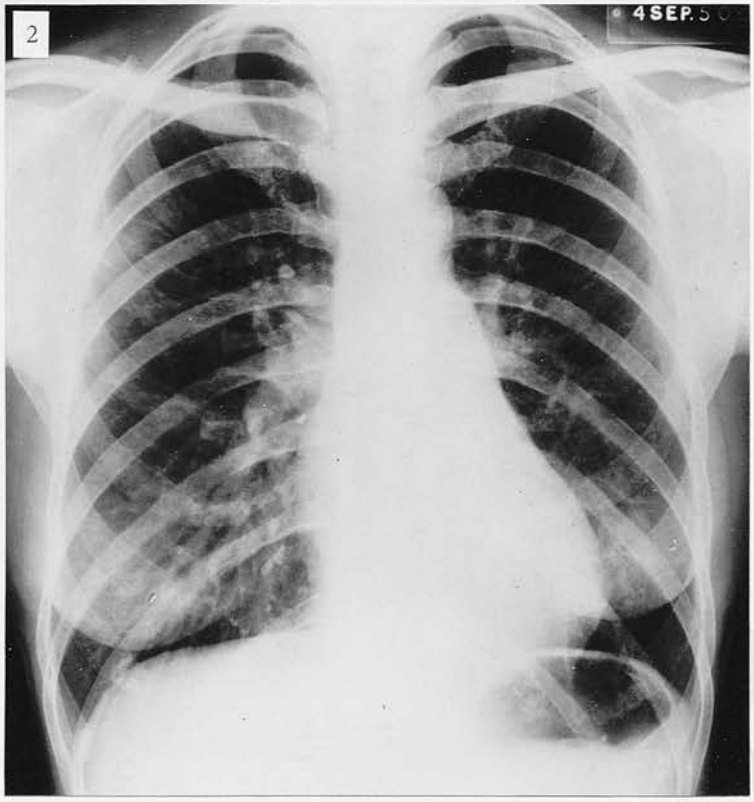


FIG. 13 Radiograph of Case 78. Moderate Ductus in fourth decade. Development of calcification in Aortic Arch.

1) P.A. age 35yrs. C.A.+26% - C.T.R.49
2) P.A. age 40yrs. C.A.+19% - C.T.R.48.2
No increase in cardiac size over 5yrs.
Prominent Pulmonary Artery.
Development of calcification low in Aortic Arch between age 35 and 40.

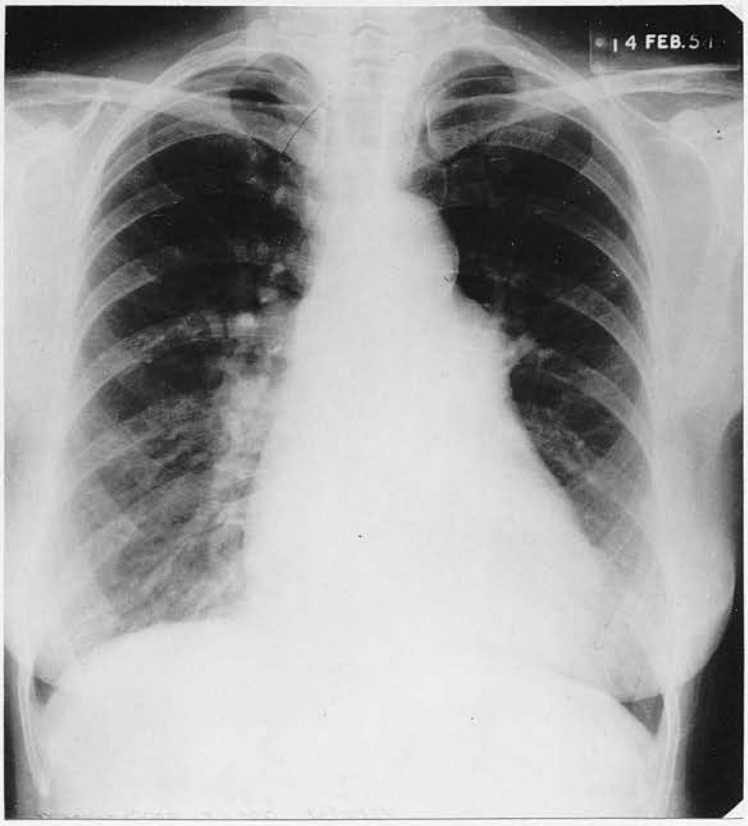
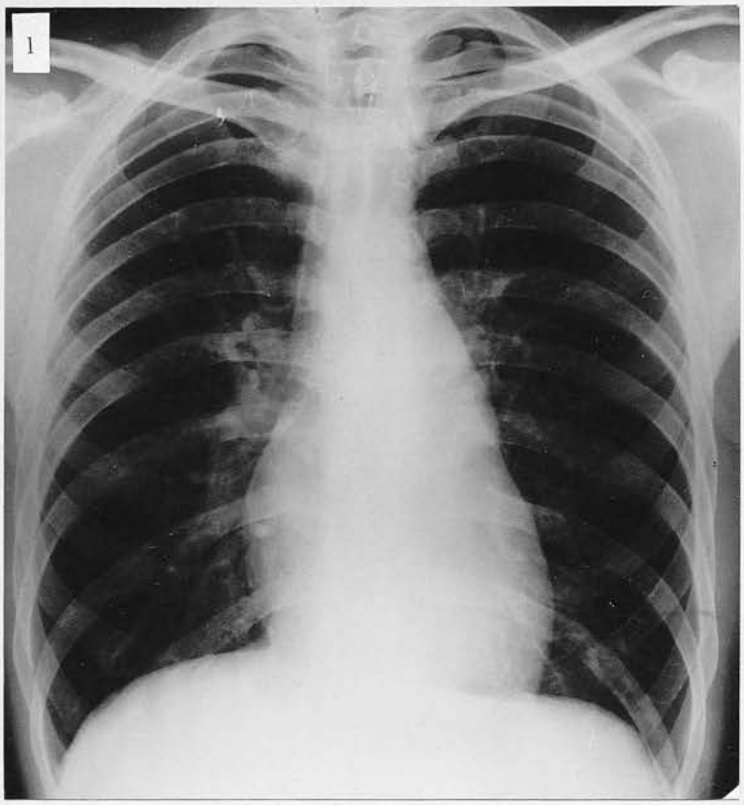


FIG. 14 Radiograph of Case 73. Characteristic appearance of Patent Ductus in fifth decade.
P.A. age 48yrs.
Marked generalised cardiac enlargement
C.A. +60%, C.T.R. 53.6
Marked prominence of Pulmonary Artery
Congestion of lung fields.
Calcification low in Aortic Arch

1)



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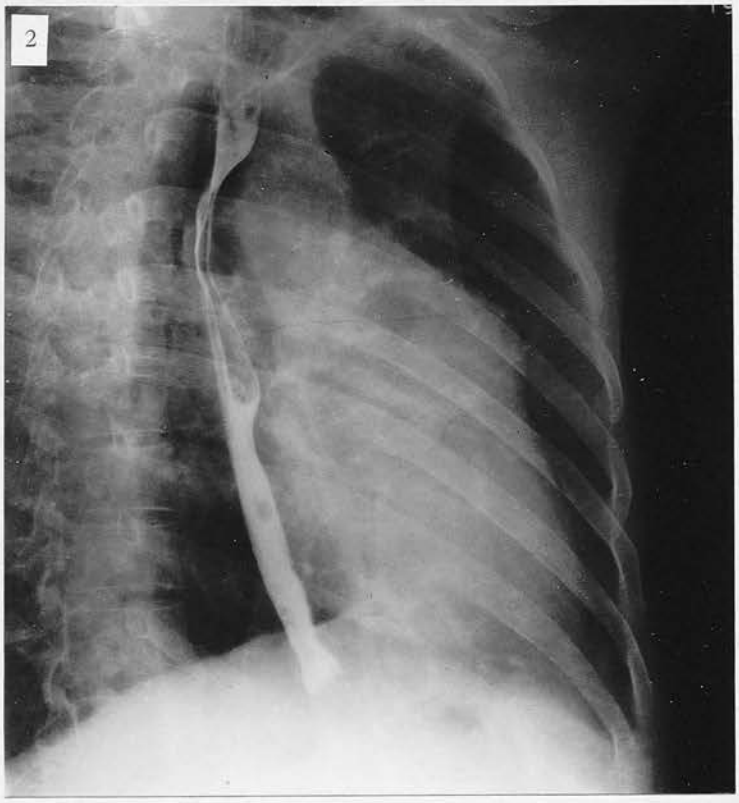


FIG. 15 Radiograph of Case 77. Unusual appearance of Pulmonary Artery in adult.
1) P.A. 2) R.A.O. age 44yrs.
Size within normal limits, C.A.+10% C.T.R.42.5
Pulmonary Artery enlarged, but mainly anteriorly

4) ELECTROCARDIOGRAPHY

Observers are agreed that in Patent Ductus Arteriosus the Electrocardiogram, using standard leads, is within normal limits and that any finding otherwise, such as gross Right Axis Deviation, should at once cast doubt on the diagnosis of uncomplicated Patent Ductus Arteriosus. Shapiro, Keys and Violante (1941), Shapiro (1944), Gilchrist (1945), Levine and Geremia (1947), Gross and Longino (1951), all base their observations on bipolar leads. Mannheimer(1950), in a review of 180 cases, using unipolar leads, notes the frequent presence of a deep S in lead V1 and a tall R in leads V4 and V5, and concludes the presence of Left Ventricular Hypertrophy in these cases.

We have seen from our radiological studies that the Left Ventricle becomes increasingly prominent in the older age group and that its presence in the younger case is frequently associated with generalised cardiac enlargement and clinical evidence of a large shunt. The early recognition of signs of Left Ventricular Hypertrophy is thus of importance, and the use of unipolar electrocardiography together with radiographic studies is of value in this respect.

Unipolar Leads - Standards of Normal Variation.

With increasing use of Unipolar Leads, standards of normal variation have been established. In a detailed study of precordial leads in the normal, Myers et al (1947) found the upper limit of QRS to be 0.098 sec., and the onset of the intrinsic deflection

to be up to 0.023 sec. in V1 and 0.05 sec. in V6. Q might occur normally in leads to the left of the precordium, but such a Q was brief in duration and in magnitude less than 25% of the amplitude of the succeeding R. R, they found to be maximal in leads V4 and V5. Sokolow and Friedlander (1949) studied the voltage of precordial leads and found the mean sum of R in V1 and S in V5 (representing the total Right Ventricular Potential) to be 3.7mm., and the mean sum of S in V1 and R in V5 (representing the total Left Ventricular Potential) to be 19.9mm.

Unipolar Leads - Ventricular Hypertrophy.

In the fully developed case, leads from points over a hypertrophied ventricle show broadening of QRS as a whole, frequently a small Q, tall R waves, ST depression and T inversion. The intrinsic deflection may be slightly delayed. Leads from points over the other ventricle tend to show unusually small R and deep S waves (Hill, 1950).

Sokolow and Lyon (1949a,b) include high voltage alone in certain leads as evidence of ventricular hypertrophy, although this is not universally accepted in the absence of ST.T changes or delay in the onset of the intrinsic deflection. Their criteria are as follows :-

Left Ventricular Hypertrophy

R in I + S in III	25mm. or more
R in aVL exceeding	11mm.
R in V5 or V6 exceeding	26mm.
S in V1 + R in V5 exceeding	35mm.

Right Ventricular Hypertrophy

R in aVR 5.0mm. or more

R in V1 + S in V5 or V6 exceeding 10.5mm.

The Electrocardiogram in the Child.

Voltage in precordial leads is normally higher in the child. Switzer and Bezoain (1950) have analysed the Electrocardiograms of 50 normal children, They found the PR interval within normal adult limits, the position of the heart most frequently vertical, Q waves in V4, V5, V6 common and on the whole deeper than in the adult, voltage of R and S in precordial leads normally higher, ST segment almost consistently elevated in V2 and V3. T may be inverted in V1 to V4 as in aVL - but in aVF almost consistently upright.

Present Study.

In this investigation the Electrocardiograms have been analysed in tabular form, particular attention being paid to Rate, Rhythm, PR Interval, Position of Heart, Voltage of Unipolar Limb and Precordial Leads with particular reference to Left Ventricular Potential, and the presence of signs of Left or Right Ventricular Hypertrophy in standard, limb or precordial leads.

Because of the differing standards, the same subdivisions as for the study of Physical Signs and Radiology have been maintained, so that groups of similar age may be studied and compared with their appropriate "normals". The "normal" figures used in the analysis which follows are based on the work already described in this chapter.

THE ELECTROCARDIOGRAM IN PATENT DUCTUS ARTERIOSUS.

PRE-SCHOOL GROUP Under 5 years

15 cases

Unipolar leads in 11

Rate:

average 107 per minute

highest 167 " "

lowest 75 " "

Rhythm:

Sinus Arrhythmia in one case (107)

Otherwise Normal Rhythm or Sinus Tachycardia

PR Interval:

average 0.14 sec.

longest 0.18 sec.

shortest 0.12 sec.

Position of Heart:

vertical 9

intermediate 1

horizontal 1

Standard Leads:

Voltage - R in I + S in III

average 15mm.

2 cases (104, 109) greater than 25mm.

ST.T Segment

1 case (105) showed 1mm. ST depression associated with diphasic T in lead III

Unipolar Limb Leads:

Voltage - R in aVF ("normal" 3-21mm.)

1 case (105) R greater than 21mm. (31mm.) and associated with deep Q and 1mm. ST depression

ST.T Segment

as above

Precordial Leads:

Voltage - a) R in V5 or V6 ("normal" 11-27mm.)

average 33mm.

maximum 54mm.

minimum 13mm.

8 cases greater than 27mm. ("normal" maximum)

b) S in V1 + R in V5 ("normal" max. 39.1mm.)

average 49mm.

maximum 80mm.

minimum 18mm.

7 cases greater than 39mm.

ST.T Segment

No abnormality

Q Waves ("normal" maximum 6, 8, 5mm. in V4, V5, V6 respectively)

2 cases showed deep Q waves

Case 50 Q, 0, 7, 7mm. in V4,V5,V6 respectively

" 109 Q, 2, 5, 6mm. in V4,V5,V6 respectively

Notching of T wave in V2, V3

5 cases

According to the standards of Switzer and Besoain (1950), eight of the 11 children showed high voltage in the precordial leads, which were otherwise within normal limits. The significance of this is, however, doubtful.

Only one child (Case 103) showed definite Left Ventricular enlargement on X-ray in this group,

and she also was the only one who showed evidence of Left Ventricular Hypertrophy in the electrocardiogram with ST depression and diphasic T in lead III, and ST depression and tall R in aVF. She also showed high voltage in the precordial leads.

A group of ten normal children of same age (siblings of cases of Patent Ductus Arteriosus) was similarly analysed.

Unipolar Limb Leads:

Voltage - R in aVF

None were above "normal", 21mm.

ST.T Segment

No abnormality

Precordial Leads:

Voltage - a) R in V5 ("normal" 11-27mm.)

average 16.5mm.

maximum 30mm.

minimum 5mm.

1 case greater than 27mm.

b) S in V1 + R in V5 ("normal" max. 39.1mm.)

average 27mm.

maximum 39mm.

minimum 11mm.

1 case 39mm.

ST.T Segment

No abnormality

Q Waves

1 case showed deep Q waves in V5 (5mm.)

Summary.

15 cases under 5 (11 with unipolar leads). No abnormal rhythm found. Only one showed Sinus Arrhythmia.

The PR Interval was within normal limits in all cases.

One case showed evidence of Left Ventricular Hypertrophy, with deep Q waves and ST depression in limb leads, deep Q waves and high voltage in precordial leads.

None showed evidence of Right Ventricular Hypertrophy.

Eight cases showed high voltage in precordial leads over Left Ventricle. This was of doubtful significance, but appeared to be a definite pattern. It was not found in siblings of the same age, only one of whom had voltage at upper limit of normal.

Notching of T waves in precordial leads occurred in five cases, but occurred equally frequently in normal children.

SCHOOL AGE GROUP a) 5 to 10 years

47 cases

Unipolar leads in 24 plus seven with leads V2, V4, V5 only.

Rate:

average 95 per minute

highest 158 " "

lowest 60 " "

Rhythm:

Sinus Arrhythmia in seven cases

Otherwise Normal Rhythm or Sinus Tachycardia

PR Interval:

average 0.15 sec.

maximum 0.20 sec.

minimum 0.12 sec.

Position of Heart:

vertical 18

intermediate 4

horizontal 1

indeterminate 2

Standard Leads:

Voltage - R in I + S in III

average 11mm.

maximum 28mm.

minimum 3mm.

2 cases greater than 25mm. (Cases 49 and 102)

ST.T Segment

Three cases showed 1mm. ST depression in lead II associated with upright T wave (34, 44, 46)

1 case (55) T flat in lead I

Unipolar Limb Leads:

Voltage - R in aVF ("normal" 4.5-14mm.)

In 13 cases R was taller than 14mm. in aVF

In one case associated with 1mm. depression of ST segment (Case 44)

In five cases associated with flat or inverted T in aVL (though this may be normal)

ST.T Segment

as noted above

3 cases in addition, with normal voltage, had inverted T in aVL.

Precordial Leads:

Voltage - a) R in V5 or V6 ("normal" 9-22mm.)

average 34mm.

maximum 69mm.

minimum 18mm.

In all but three R was above 22m. in height.

b) Sum of S in V1 plus R in V5 ("normal" maximum 39mm.)

average 58mm.

maximum 109mm.

minimum 26mm.

Again only three (same three as above) fell below "normal" maximum of 39.

Measurement of cardiac area on the X-rays of these three children showed them all to be within normal limits (+2%, +10%, and -6% respectively)

ST.T Segment

Two children who did not have complete unipolar sets showed changes

Case 34 showed 2mm. ST depression in V4 and 3mm. ST depression in V5 with upright T in both

Case 36 showed no ST changes, but had diphasic T in V4 and V5

Q Waves

Deep Q waves were seen in five cases, all with

very high voltage, as below :-

	Q	V4	V5	V6	R in V5 + S in V6	R in V5
Case 39		0mm.	5mm.	6mm.	109mm.	69mm.
" 46		0	3	5	60	28
" 58		6	11	9	108	50
" 93		2	5	8	54+	36+
" 100		0	10	9	72+	48+

Notching of T wave

14 cases showed this in V2, V3, V4

A group of six <u>normal children</u> of the same age (siblings of cases of Patent Ductus Arteriosus) were similarly analysed.

Three showed R in aVF to be above "normal" maximum of 14mm. (16, 16, 19mm. respectively)

Three showed high voltage in left precordial leads as estimated by height of R in V5 (above 22mm.), and this was also shown by two cases estimating by the sum of R in V5 and S in V6 (above 39mm.).

None showed ST.T changes in any leads, or deep Q waves.

<u>Summary</u>.

47 cases between 5 and 10yrs. (31 with unipolar leads)

None of the cases showed abnormality of rhythm. Seven had Sinus Arrhythmia.

The PR interval was within normal limits in all cases.

In four cases the appearances suggested Left Ventricular Hypertrophy :-

Case 34 - 1mm. ST depression in lead II, 2mm. depression in V4, 3mm. in V5. No T changes.

Case 44 - 1mm. ST depression in lead II, 1mm. ST depression in aVF. No T changes.

Case 46 - 1mm. ST depression in II, very high voltage in precordial leads.

Case 36 - No ST changes but diphasic T in V4 and V5.

No case showed evidence of Right Ventricular Hypertrophy.

As judged by the standards of Switzer and Bescain (1950), only three cases failed to show high voltage in the precordial leads. Examination of the electro-cardiograms of normal siblings suggests, however, that high voltage is not uncommon amongst normal children at this age, and therefore its presence is of doubtful significance.

Fig. 16 shows the voltage in the precordial leads in relation to the Cardiac Area as measured on the X-ray. It is to be noted that no case showing voltage (S in V1 + R in V5) above 60 has a cardiac area within normal limits.

SCHOOL AGE GROUP b) 10 to 16 years.

21 cases

Unipolar leads in 11 plus one with leads V2,V4,V5 only

Rate:

average	84	per minute
highest	108	" "
lowest	57	" "

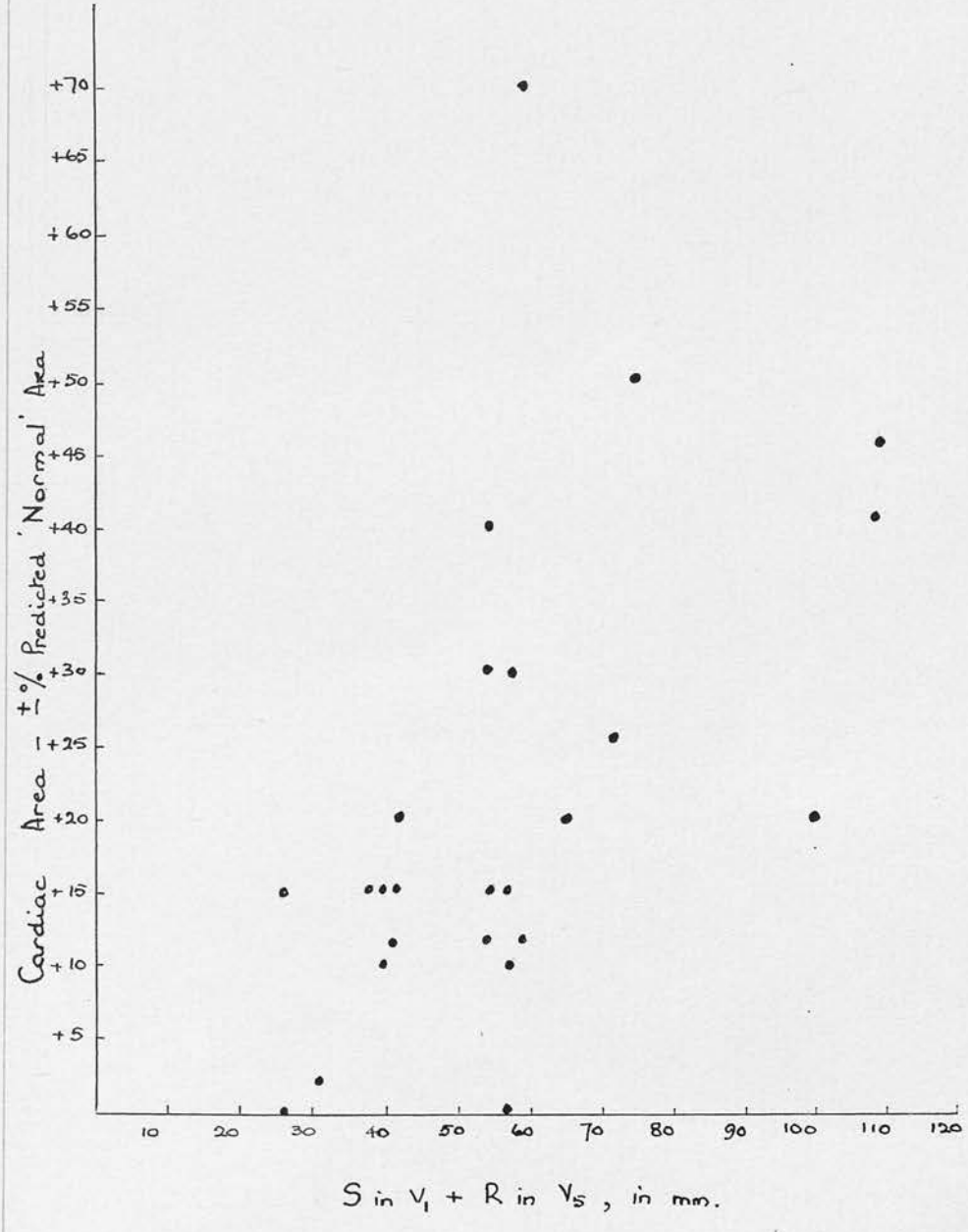


FIG. 16 Voltage of precordial leads, as estimated by sum of S in V1 and R in V5, in relation to Cardiac Area (Age 5 to 10 years)

Rhythm:

Sinus Arrhythmia in one case

Sinus Bradycardia in one case

Otherwise Normal Rhythm or Sinus Tachycardia

PR Interval:

average 0.16 sec.

maximum 0.18 sec.

minimum 0.12 sec.

Position of Heart:

vertical 9 cases

horizontal 2 cases

Standard Leads:

Voltage - R in lead I + S in lead III

average 15mm.

maximum 25mm.

minimum 7mm.

ST.T Segment

One case (68) showed 1mm. ST depression in I and II with upright T wave,

One case (45) showed 1mm. ST depression in I with diphasic T,
2mm. ST depression in II and III with diphasic T in II and upright T in III

One case (43) showed 0.5mm. ST depression in II with upright T

Unipolar Limb Leads:

Voltage - R in aVL, "normal" 0.5-6mm.

R in aVF, "normal" 2-14mm.

High voltage was seen in three cases, i.e. R in

aVF greater than 14mm. In one it was associated with 1mm. ST depression and upright T (Case 45). The other two cases (64, 65) showed no ST.T changes.

ST.T Segment

In addition to Case 45 mentioned above, two showed 1mm. ST depression in aVF with normal voltage and upright T waves (Cases 68, 91).

Precordial Leads:

Voltage - a) R in V5 or V6 ("normal" 9.5-22.0mm.)

average 30mm.

maximum 52mm.

minimum 14mm.

9 fell above "normal" maximum of 22.0mm.

b) Sum of S in V1 and R in V5 ("normal maximum 39mm.)

average 57mm.

maximum 107mm.

minimum 27mm.

7 cases greater than normal maximum of 39mm.

ST.T Segment

Two cases showed depression of the ST segment in the left precordial leads

Case 45 - 2mm. ST depression in V5 and V6 with diphasic T and deep Q waves

Case 68 - 2mm. ST depression in V6 with upright T and normal Q waves

Q Waves

Deep Q waves seen in three cases, two with evidence of Left Ventricular Hypertrophy, one

with high voltage only

Notching of T waves

This was seen in seven cases in V2, V3, V4

Summary.

No abnormal rhythm seen. Only one case showed Sinus Arrhythmia.

The PR interval was within normal limits in all cases.

Two cases showed definite evidence of Left Ventricular Hypertrophy,

Case 68 with tall R, ST depression and diphasic T in V6,
tall R, ST depression and upright T in aVF,
ST depression in Leads I and II with upright T

Case 45 with deep Q, tall R, ST depression and diphasic T in V5 and V6,
tall R, ST depression and upright T in aVF,
ST depression I,II,III with diphasic T in leads I and II.

A third case (43) was suggestive of Left Ventricular Hypertrophy with ST depression and inverted T wave in aVF, ST depression with upright T in Lead I.

It is noteworthy that the two cases showing definite evidence of Left Ventricular Hypertrophy are also the two with the highest voltage in this group. The third case, though less marked, also has voltage above normal.

No case showed evidence of Right Ventricular Hypertrophy.

Fig. 17 shows voltage in relation to cardiac area. Again it will be noted that cases with high voltage, with one exception, are all associated with cardiac area above normal, and that those with highest voltage show the greatest cardiac area.

ADULT GROUP 16 years and over

35 cases

Unipolar leads in 18 plus one with leads V2,V4,V5 only and one not accurately standardised.

Rate:

average 78 per minute

highest 125 " "

lowest 50 " "

Rhythm:

Auricular Fibrillation 4 cases - one restored to Normal Rhythm

Extra systoles (multiple) 1 case

Normal rhythm 30 cases

including Sinus Arrhythmia 2 cases

" Bradycardia 2 cases

" Tachycardia 1 case

PR Interval:

average 0.18 sec.

maximum 0.22 sec. (increasing to 0.28 sec. after exercise)

minimum 0.12 sec.

All cases above 45 years had PR interval of 0.20 seconds unless fibrillating

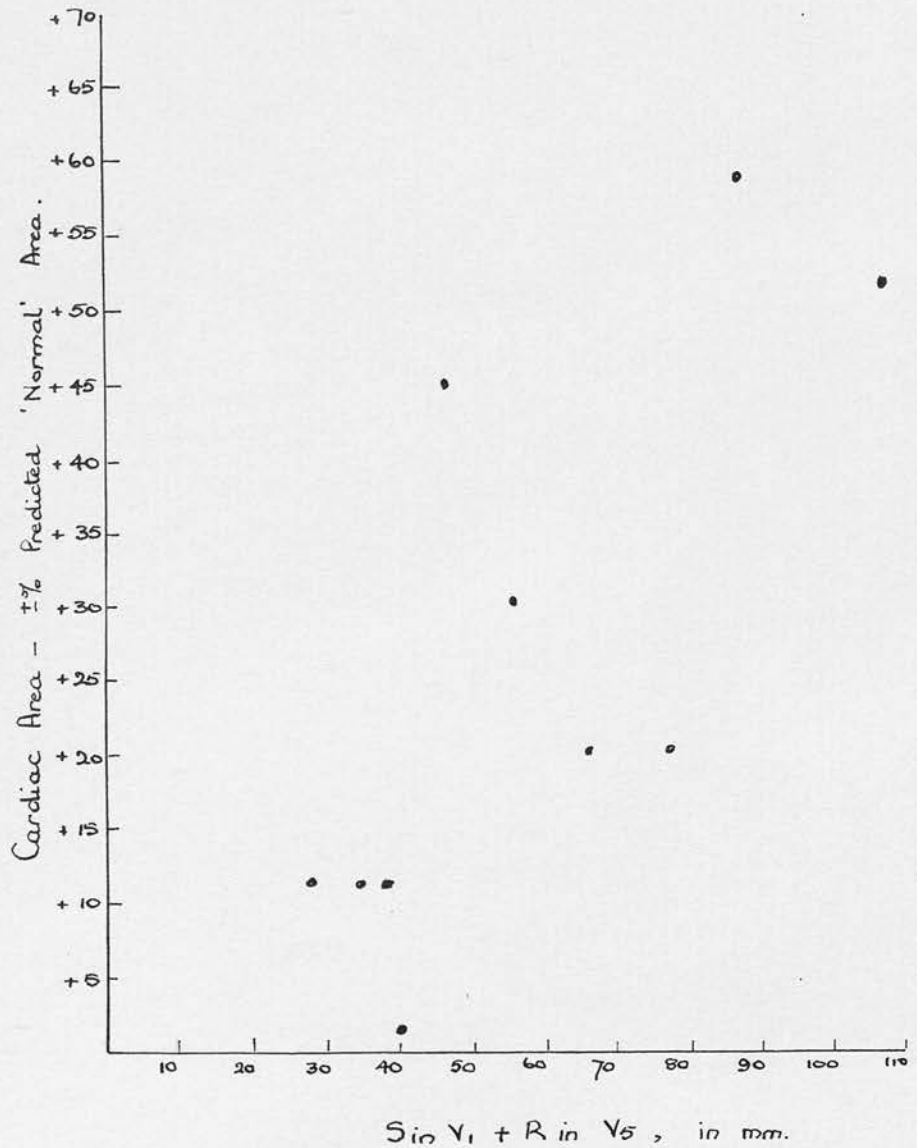


FIG. 17 Voltage of precordial leads as estimated by sum of S in V1 and R in V5, in relation to cardiac area (Age 10 to 15 years)

Position of Heart:

vertical 9

horizontal 7

indeterminate 4

Standard Leads:

Voltage - R in I + S in III

average 15mm.

maximum 38mm.

minimum 6mm.

ST.T Segment

Six showed changes: four of these were over 40yrs.

Case 84 aged 27 1mm. ST depression, upright T lead I

" 79 " 38 1mm. ST depression, inverted T " I

" 74 " 48 1mm. ST depression, inverted T " I

" 73 " 48 0.5mm, ST depression diphasic T " I

" 72 " 55 1mm. ST depression inverted T " I

" 71 " 64 1mm. ST depression inverted T " I

None showed T changes without ST depression

Unipolar Limb Leads:

Voltage - R in aVL normal maximum 11mm.

R in aVF normal maximum 20mm.

Three cases (79, 72, 71) showed high voltage in aVL in each case, associated with 1mm. ST depression and inversion of T (all had horizontal hearts). These cases had already been noted to have changes indicative of Left Ventricular Hypertrophy in the standard leads.

ST.T Segment

As above

Precordial Leads:

Voltage - a) R in V5 or V6 ("normal" maximum 26mm.)

average 24mm.

maximum 38mm.

minimum 12mm.

8 cases showed high voltage R in V5 or V6

Case 59 aged 17 R 28mm. Deep Q waves V5,V6 - no ST.T changes

" 70 " 25 R 29mm. ST depression V5, V6

" 84 " 27 R 26mm. ST depression V4, V5, V6

" 79 " 38 R 38mm. ST depression and diphasic T V5, V6

" 78 " 40 R 34mm. ST depression and diphasic T V4, V5, V6

" 72 " 55 R 27mm. ST depression, diphasic T V5, inverted T V6

" 71 " 64 R 25mm. ST depression, T inversion V5, V6

Thus, six of these eight cases showing tall R waves over left precordial leads show in addition ST.T changes suggestive of Left Ventricular Hypertrophy.

b) S in V1 + R in V5 ("normal" maximum 35mm)

average 45mm.

maximum 91mm.

minimum 27mm.

All but three cases showed voltage above normal. According to Sokolow and Lyon (1949,a), this is indicative of Left Ventricular Hypertrophy. Only seven, however, showed the ST.T changes

associated with Left Ventricular Hypertrophy. These were Cases 70, 84, 79, 73, 72, 71, already described. In addition, Case 74 had ST depression with T inversion in V5 and V6 (voltage not accurately standardised but probably high).

Q waves

Only one in this group showed deep Q waves (Case 59, aged 17 years, with Q 7mm. deep in V6 followed by R 28mm. tall).

Bundle Branch Block

One case in this group (75) showed evidence of partial Right Bundle Branch Block - and proved at Post Mortem to have had a Stomal Ductus with shunt reversal and hypertrophy of both Ventricles. ST depression and T inversion seen in leads to the left of the precordium were considered to be Digitalis effects.

Summary.

In contrast to the younger groups, abnormal rhythm (auricular fibrillation) was seen in four cases, with an additional case with a complex extra-systolic arrhythmia.

In six cases, aged 18, 19, 21, 35, 48 and 55 respectively, the PR interval was above normal (0.18 sec). Latent heart block is thus a feature in this older group.

All but three cases showed high voltage as estimated by the sum of S in V1 and R in V5. Of these, seven showed changes in the left precordial

leads indicative of Left Ventricular Hypertrophy. The average voltage in those with ST.T changes was 55.5mm. compared with 41.0mm. for those without ST change and 45mm. for the group as a whole. Only one case (70), who showed moderately high voltage, ST depression with upright T waves in V5 and V6, has been confirmed pathologically. Radiologically, the cardiac area was only +15%. At Post Mortem, though the heart was not grossly enlarged, there was very marked Left Ventricular Hypertrophy present. This had been reflected in the electrocardiogram in the precordial leads overlying the Left Ventricle.

Fig. 18 shows voltage of precordial leads in relation to cardiac area.

SUMMARY

Table XXII summarises the electrocardiographic findings in 110 cases of Patent Ductus.

It illustrates the tachycardia which is characteristic of this condition, gradually lessening as the older groups are reached.

Abnormal rhythm is rare before adult life. In later life, auricular fibrillation is the most common arrhythmia, being seen in four cases. Sinus Arrhythmia is not often seen, only 11 cases showing it.

The PR interval gradually lengthens throughout childhood - and a PR interval of 0.20 or over was seen in no fewer than six of the adult group, two in young adult life.

A vertical heart was the usual finding in

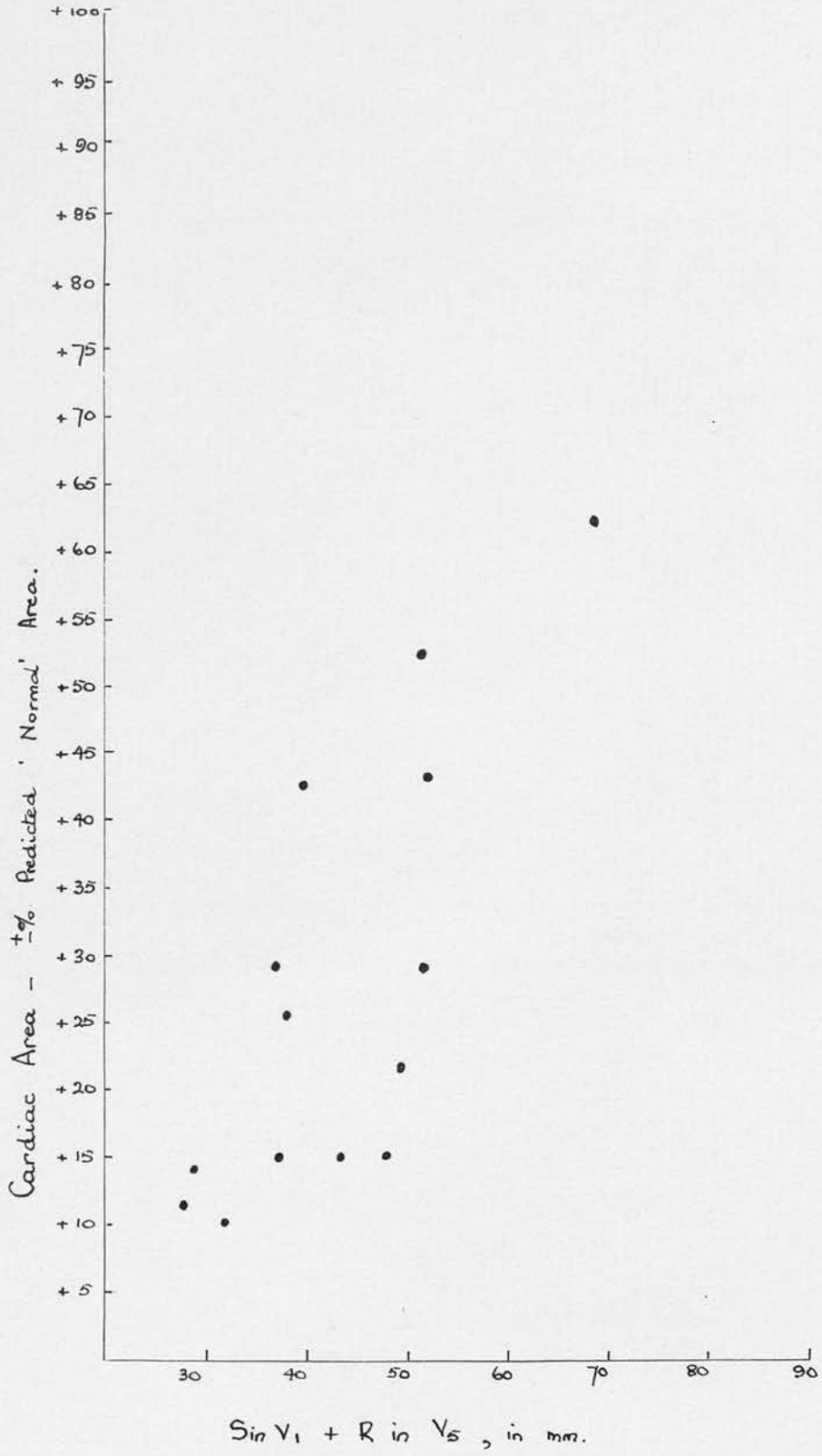


FIG. 18 Voltage of precordial leads as estimated by sum of S in V1 and R in V5 in relation to cardiac area (Age 16 years and over)

the pre-school and school child, but in adult life over 40% were horizontal.

High voltage in the unipolar limb leads and in precordial leads over the Left Ventricle is a frequent finding at all ages. In the adult, this may suggest left ventricular enlargement (Sokolow and Lyon, 1949,a) and there is evidence in this study to suggest that this is so. In the child in the absence of adequate standards it is difficult to assess what is meant by high voltage, and having done so to estimate its significance. The larger electrical deflections in the child may result not only from left ventricular enlargement but also as a result of the anatomical position of the heart, the thinness of the chest wall, and the closer position of the heart with relation to the anterior wall of the chest. Whatever the significance, it is a pattern seen in this defect and particularly in the under-5 group its presence may be of value in the differentiation of the difficult case. Left Ventricular Hypertrophy is seen with increasing frequency in the older groups, although even in the adult group unequivocal signs are only seen in 38% of the group as a whole, though the percentage increases in each decade.

Notching of T waves in precordial leads is a well marked feature in this series but has been recognised as a normal feature in childhood, possibly due to the greater proportionate size of Right Ventricle to the Left and its closer proximity to the chest wall, possibly also to the more transverse

position of the septum.

Deep Q waves noted in several cases in leads over the left precordium were all followed by a tall R wave, and were therefore not strictly abnormal.

Figs. 19 - 25, which follow, illustrate the electrocardiographic findings in Patent Ductus Arteriosus from infancy to old age.

TABLE XXII

Electrocardiographic Findings in 110 cases of Patent Ductus Arteriosus

Age Groups	Under 5 years	5 to 10 years	10 to 16 years	16yrs.and older
No. of cases	15	47	21	35
Unipolar Leads	11	24 + 7	11	18 + 2
Rate				
average	107 p.min.	95	84	78
highest	167 p.min.	158	108	125
lowest	75 p.min.	60	57	50
Rhythm				
Normal	all	all	all	30
Sinus Arrhythmia	1 case	7	1	2
Auricular Fibrillation	0	0	0	4
Extra Systolic	0	0	0	1
PR Interval				
average	0.14 sec.	0.15	0.16	0.18
longest	0.18 sec.	0.20	0.18	0.22
shortest	0.12 sec.	0.12	0.12	0.12
Electrical Position				
horizontal	1 case	1	2	7
vertical	9 cases	18	9	9
Standard Leads /				

TABLE XXII (Contd.)

Age Groups	Under 5 years	5 to 10 years	10 to 16 years	16yrs. and older
Standard Leads				
R1 + SIII average	15mm.	11	15	15
ST.T changes of L.V.H.	1 case (9%)	3 (10%)	3 (27%)	6 (33%)
Unipolar Limb Leads				
No. with high voltage	1 case	13	3	3
ST.T changes of L.V.H.	1 case (9%)	1 (4%)	3 (27%)	3 (17%)
Precordial Leads				
Voltage R V5, V6				
average	33mm. (27)	34 (22)	30 (22)	24 (26)
maximum	54mm.	69	52	38
minimum	13mm.	18	14	12
No. with high voltage	8 cases (75%)	21 (87%)	9 (82%)	8 (44%)
Voltage S(V1) +R(V5)				
average	49mm. (39)	58mm.(39)	58mm.(39)	45mm. (35)
maximum	80mm.	109	107	91
minimum	18mm.	26	27	27
No. showing high voltage	7 cases (64%)	21 (87%)	7 (64%)	15 (83%)
ST.T changes of L.V.H.	nil	3 (10%)	2 (18%)	7 (38%)
Deep Q Waves	2 cases	5	3	1
Notched T Waves	5 cases	14	7	0
Partial Right Bundle Branch Block	0 cases	0	0	1

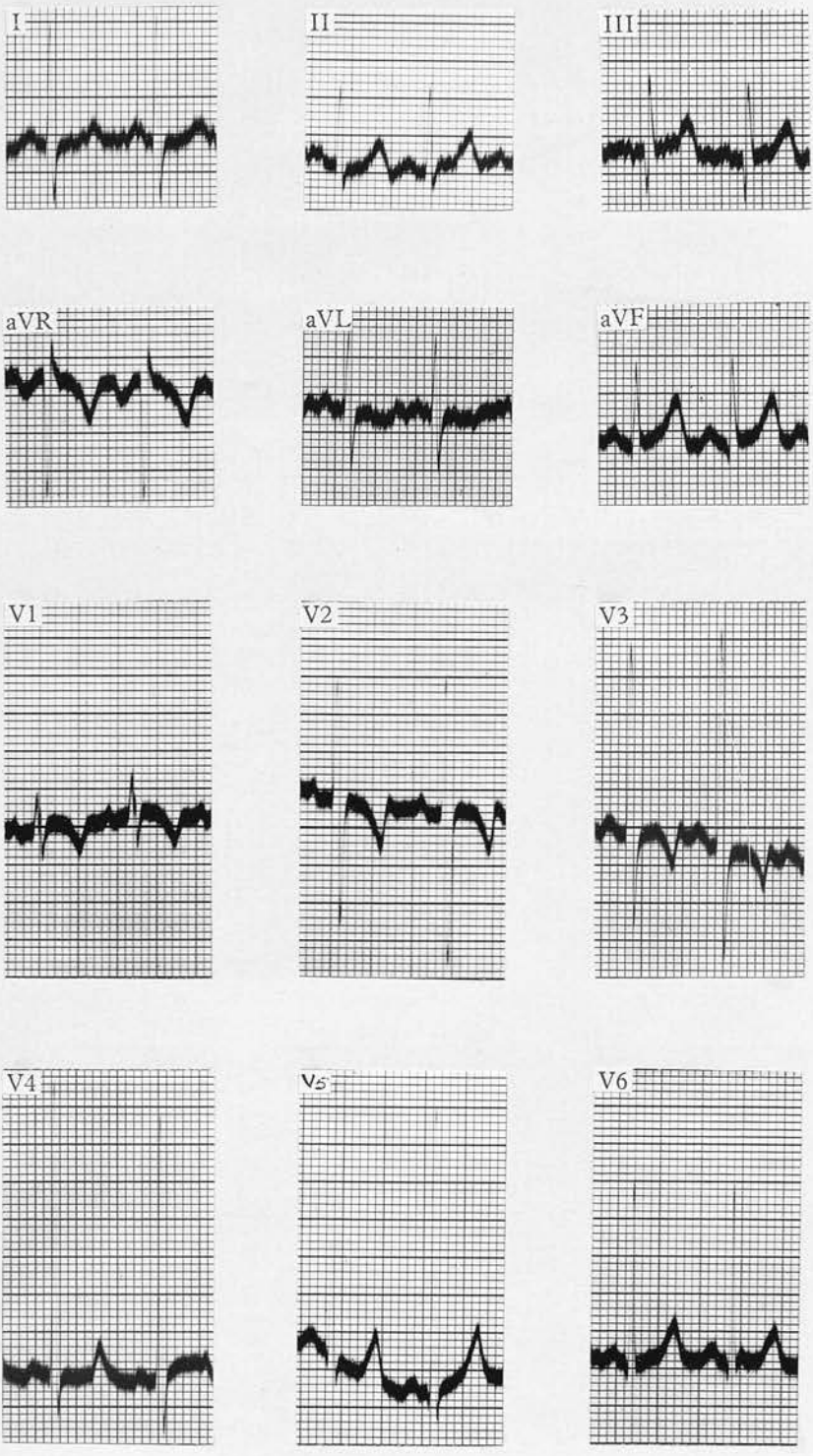


FIG. 19 Electrocardiogram of Case 110 aged 9 months.
High Voltage.

Tall R in V5
Notching of T wave V2, V3
No definite evidence of L.V.H.

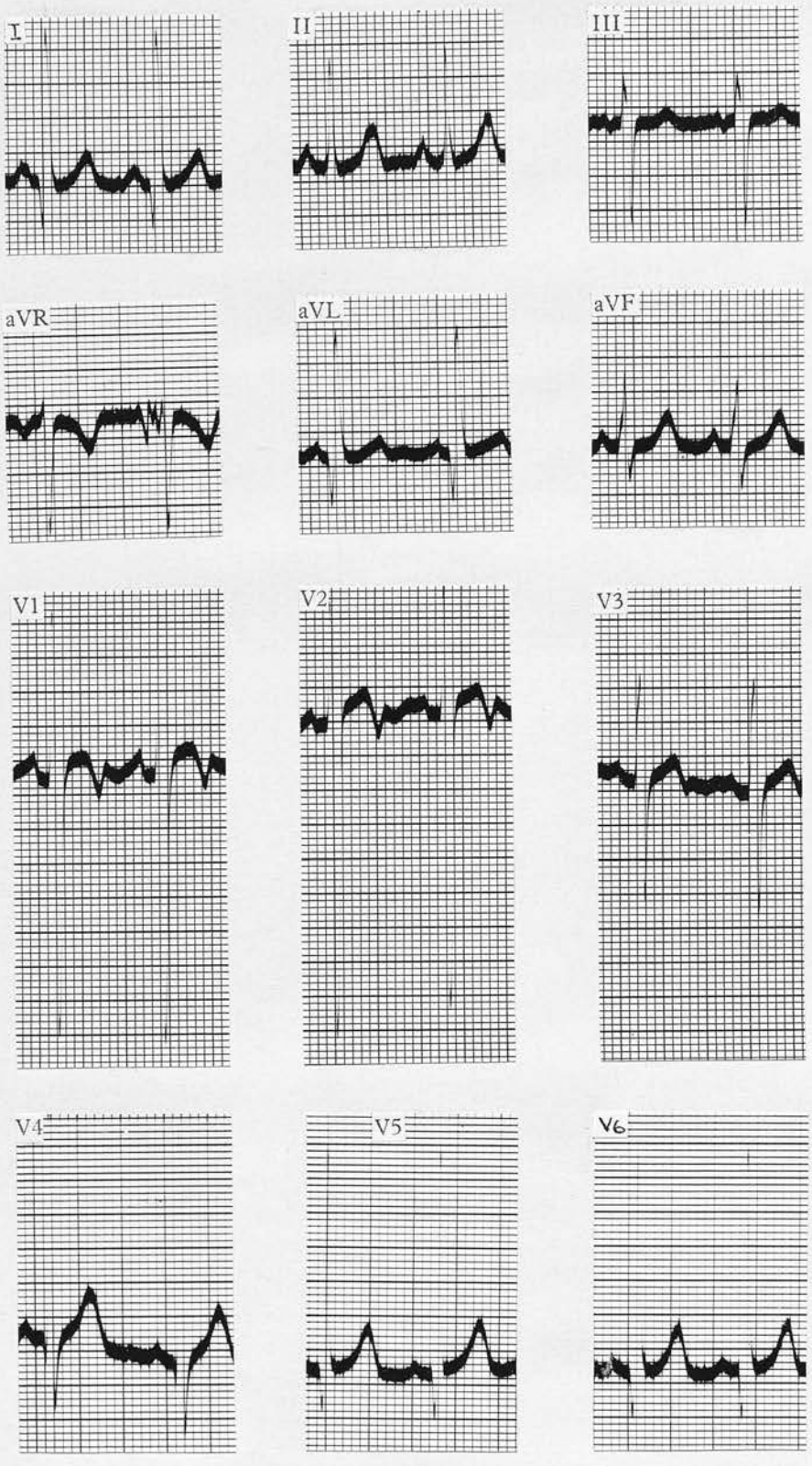


FIG. 20 Electrocardiogram of Case 109 aged 2½yrs.
High Voltage - Horizontal Heart
Deep Q, tall R V5,V6
R in V5 + S in V1 = 67mm.
Notching of T waves V1,V2,V3
X-ray shows very large heart
Clinical signs very coarse

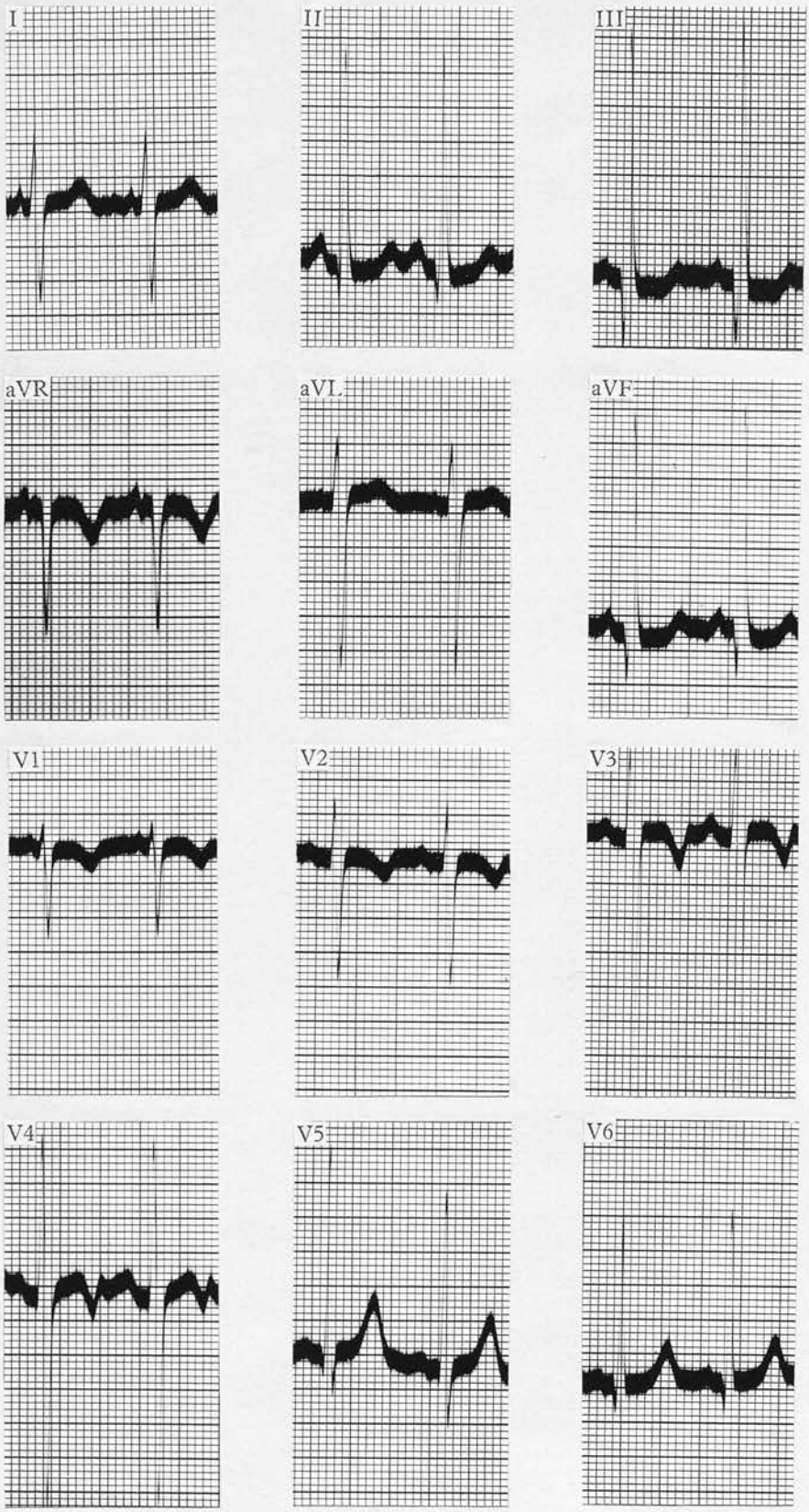


FIG. 21 Electrocardiogram of Case 105 aged 4yrs.
High Voltage. Early Left Ventricular Hypertrophy.
Tall R V5, R in V5 + S in V1 = 41mm.
Notching of T waves V3, V4
Evidence of L.V.H. in III and aVF
X-ray shows Left Ventricular Hypertrophy (Fig. 9)

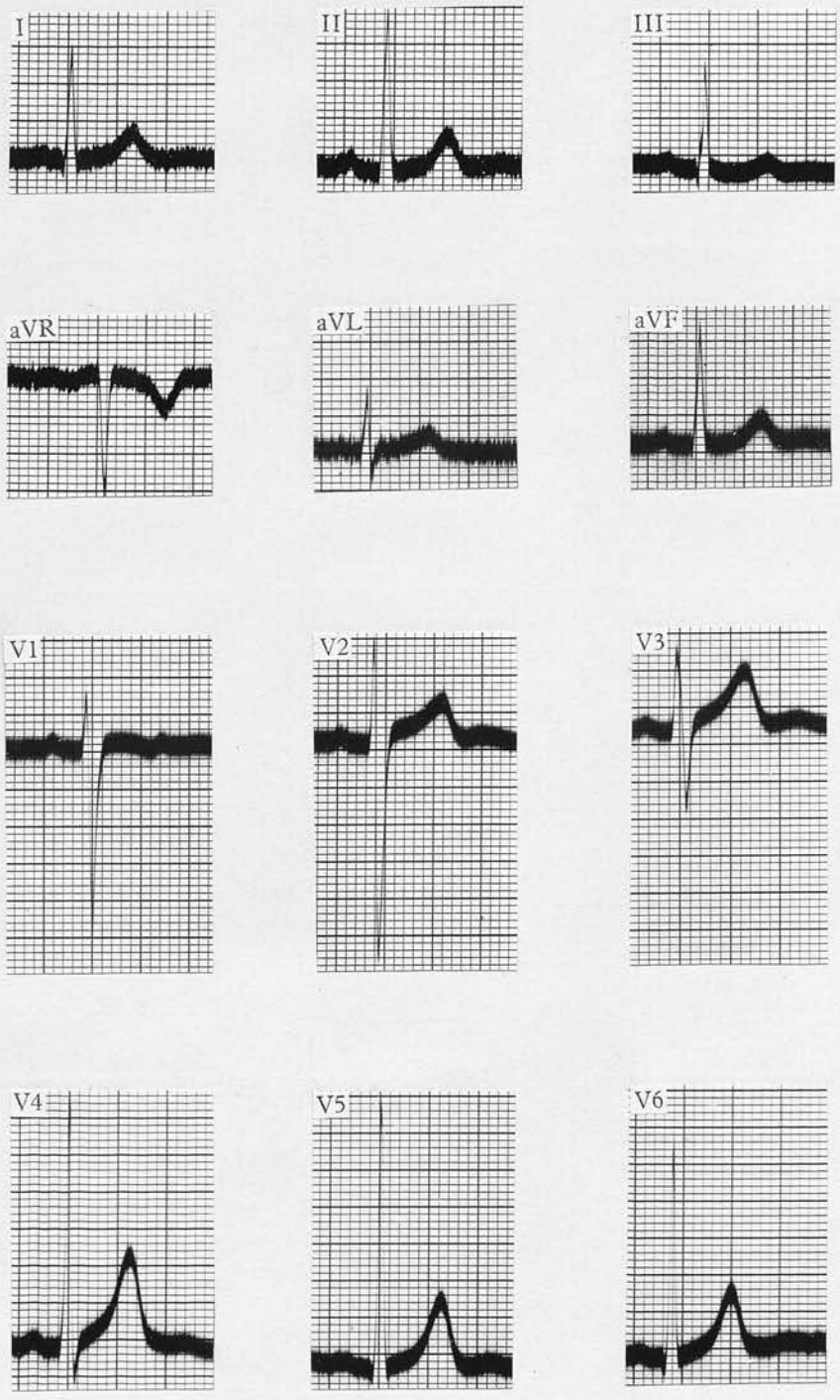


FIG. 22 Electrocardiogram of Case 78 aged 35yrs.
High Voltage.
Normal Rhythm PR 0.16 sec.
Tall R V5 V6, R in V5 + S in V1 = 50mm.
Tall R aVF
No other evidence of Left Ventricular Hypertrophy
X-ray shows slight generalised enlargement(Fig.13)

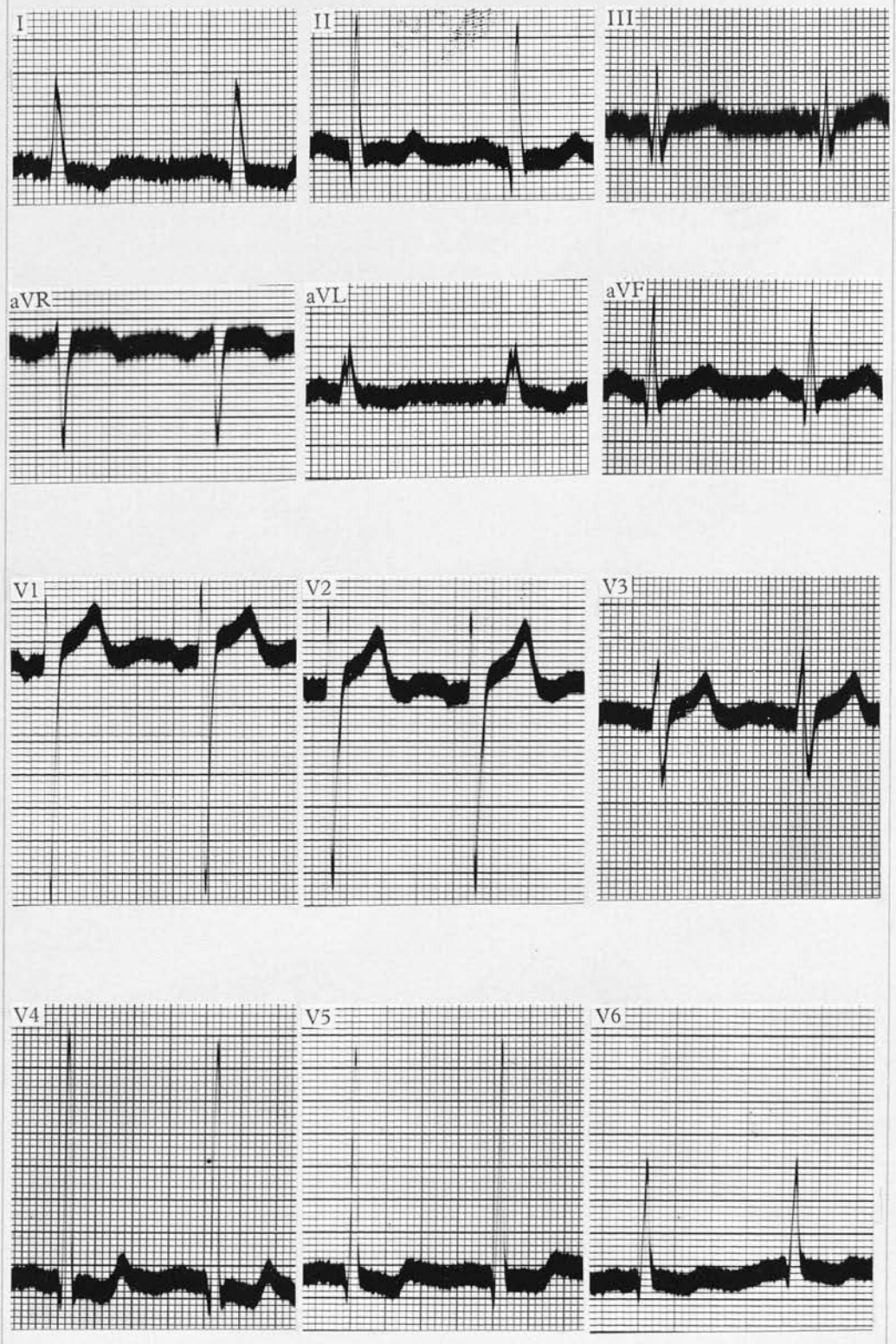


FIG. 23 Electrocardiogram of Case 73 aged 48yrs.
High Voltage. Left Ventricular Hypertrophy.
Normal Rhythm PR 0.20 sec.
Deep S in V1 and tall R V5
Evidence of L.V.H. in I, aVL, V4,V5,V6
X-ray shows gross cardiac enlargement (Fig. 14)

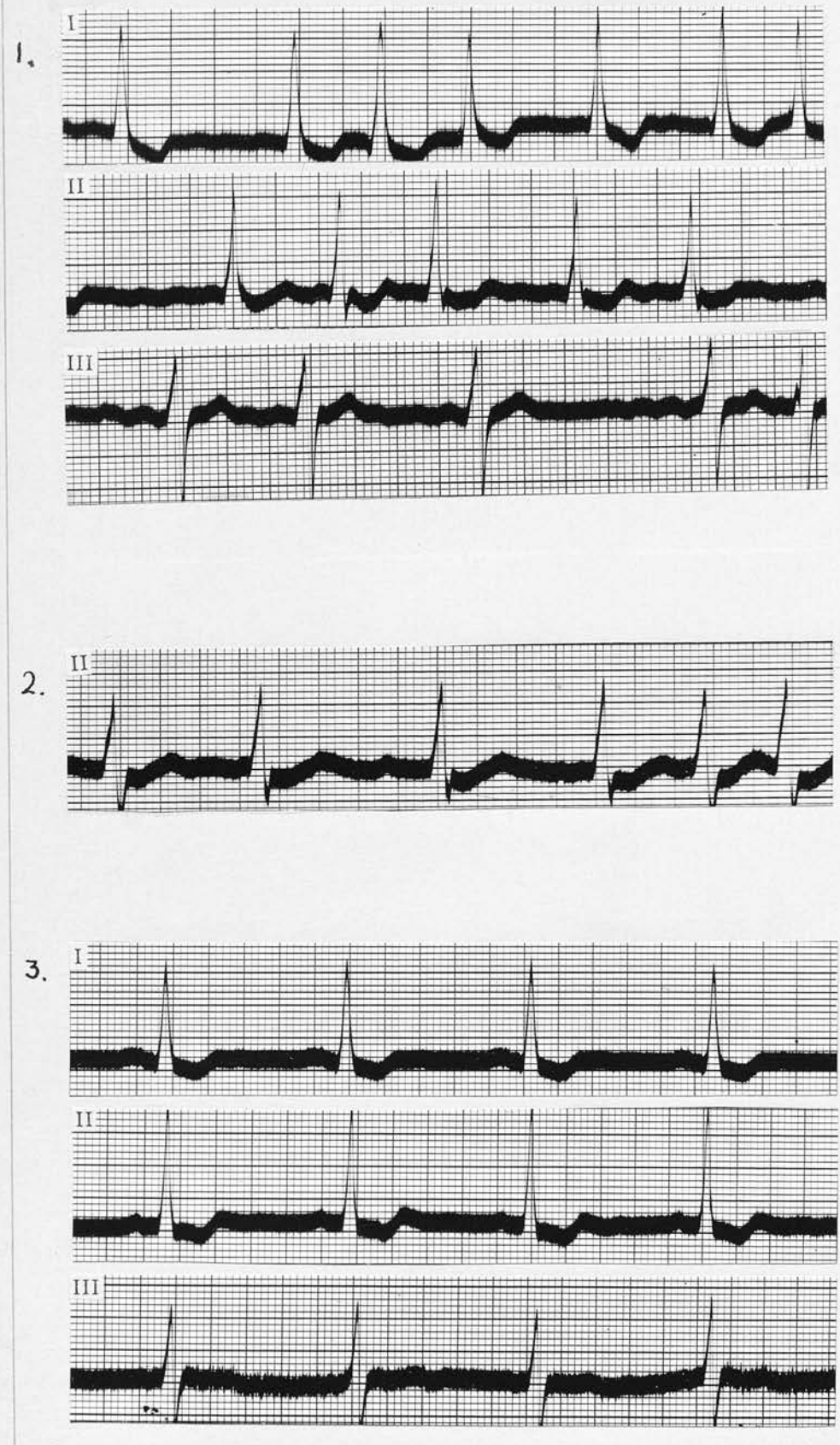


FIG. 24 Electrocardiogram of Case 79 aged 38yrs.
Abnormal rhythm - Auricular Fibrillation.
1. Auricular fibrillation with Digitalis effects
2. Transition between fibrillation and flutter under Quinidine
3. Restoration of normal rhythm

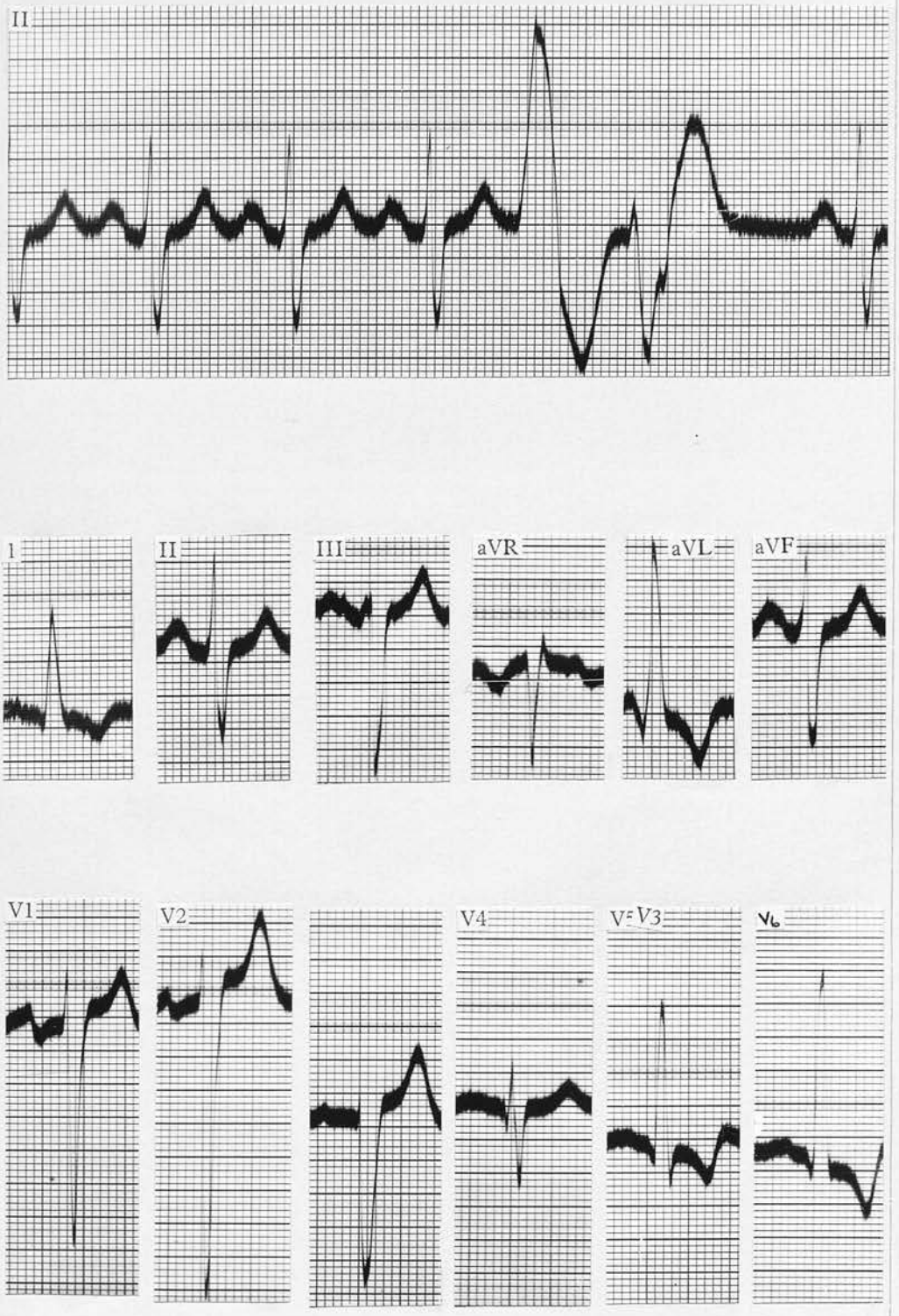


FIG. 25 Electrocardiogram of Case 72 aged 55yrs.
Abnormal rhythm - Multiple Extrasystoles
Multiple Extrasystoles
S in V1 + R in V5 = 51mm.
Evidence of L.V.H. in I, aVL, V5, V6
P.R. Interval 0.22 sec.

THE NATURAL HISTORY OF PATENT DUCTUS ARTERIOSUS (Contd.)

PREGNANCY

Incidence.

Pregnancy occurred in 14 women in this series. 13 of these had uncomplicated Patent Ductus Arteriosus while the fourteenth had had ligation of the Ductus carried out 16 months previous. In four, pregnancy occurred once; in four, twice; in four, three times; in one, four times, and in one seven times, making a total of 35 pregnancies.

Grading.

Grading during pregnancy was IIa in all cases but two -

Case 87, aged 22yrs., with signs suggesting a very large shunt, was breathless and developed ankle oedema towards the end of pregnancy (IIb).

Case 76, aged 42yrs., in whom Patent Ductus Arteriosus was complicated by diastolic hypertension, developed signs of congestive failure (IIb) early in her fourth pregnancy, which was accordingly terminated. The first two pregnancies had been uneventful. After the third, aged 37, she had been tired and breathless.

Two cases who were Grade IIa during pregnancy became IIb shortly after delivery -

Case 73, aged 35yrs., developed congestive failure two months after delivery. Two previous pregnancies had given no trouble.

Case 82, aged 35yrs., developed extreme tiredness and

breathlessness following delivery of her second child.

Three other cases are worthy of note -

Case 21, aged 27yrs., developed bacterial endarteritis after her third pregnancy.

Case 81 had seven children before she was 29 years of age. This woman was not really fit and very under-nourished, but would not admit to any disability and went out to work daily in addition to bringing up her seven children.

Case 42, aged 26yrs., had her first baby 16 months after ligation of Patent Ductus Arteriosus. Labour was prolonged on account of uterine inertia but gave rise to no anxiety. There was marked tachycardia during delivery, which quickly settled. No hypertension.

Age Incidence.

Of 35 pregnancies five occurred in the fourth and fifth decades.

Breathlessness and tiredness developed in two, and congestive failure in one following delivery. One developed congestive failure during pregnancy. One had only minor breathlessness throughout.

Of the 30 remaining pregnancies, which occurred under 30 years, in one only did congestive failure develop. One woman had seven children without difficulty.

Pregnancy is thus well tolerated in the third decade, but the strain comes in the fourth decade, particularly after delivery.

Offspring.

As a result of these pregnancies there were 34 live births. Two babies were cyanosed and died in the neo-natal period. No Post-mortem was carried out in either case to confirm the presence of heart disease. The other 32 were said to be healthy. Sixteen of them were examined and no cardiac lesion or other abnormality found.

SUMMARY.

Pregnancy is well borne in the third decade. Of 30 pregnancies only one developed signs of congestive heart failure.

In the fourth and fifth decades, however, four out of five developed symptoms and signs of failure either during pregnancy or immediately after delivery.

Two babies were cyanosed and died shortly after birth.

One case delivered 16 months after ligation of Patent Ductus Arteriosus was uneventful.

LIGATION OF PATENT DUCTUS ARTERIOSUS

70 cases of the preceding series have been submitted to operation for ligation of Patent Ductus. Originally, cases showing disability or deterioration were selected, but later in the series many symptom-free school-children were included. Above 20 years, operation was not advised in the absence of definite indication such as infection, although two women, aged 25 years, elected to have ligation carried out, preferring an immediate risk to an unknown future. Operation was advised in all cases with infective endarteritis of the Pulmonary Artery.

The youngest case was 4 years of age, with mild symptoms of breathlessness and fainting attacks, and the oldest 32 years, with infection of Pulmonary Artery superimposed. In the whole series there were seven deaths, a mortality rate of 10%. Two occurred in children aged 5 years, both severely handicapped; two at the age of 19 years, both infected; one at the age of 25 years in a woman who had shown slight deterioration over two years; one aged 28 years and one aged 32 years, both gravely ill with superadded infection. There were thus three deaths in the 61 non-infected cases (4.9%) and four in the nine infected cases (44%). Five of the deaths occurred in patients over 18 years of age. Table XXIII gives detail of the age incidence of cases submitted to operation, of infected cases and of deaths during or following on operation.

TABLE XXIII

Age Incidence of Cases submitted to Ligation of Patent Ductus Arteriosus

Incidence of Infected Cases

Incidence of Deaths during or following Operation

Age	No. of cases	Non-infected	Deaths	Infected	Deaths	Total Deaths
4	2	2	0	0	0	0
5	7	7	2	0	0	2
6	7	6	0	1	0	0
7	9	8	0	1	0	0
8	6	6	0	0	0	0
9	6	6	0	0	0	0
10	2	2	0	0	0	0
11	7	7	0	0	0	0
12	1	1	0	0	0	0
13	4	4	0	0	0	0
14	4	4	0	0	0	0
15	0	0	0	0	0	0
16	2	1	0	1	0	0
17	1	1	0	0	0	0
18	2	2	0	0	0	0
19	2	0	0	2	2	2
20	0	0	0	0	0	0
20+	8	4	1	4	2	3
Total	70	61	3	9	4	7

LIGATION OF PATENT DUCTUS ARTERIOSUS. TECHNIQUE.

Pre-operative Treatment - This was considered to be of first importance, particularly the elimination of sepsis in mouth, nose or throat. As has been mentioned earlier, this sometimes proved a difficult task. After the introduction of Penicillin, this was used as prophylactic cover but on the whole it was felt that it was equally satisfactory to reserve the use of Penicillin for any case which needed much post-operative interference, e.g., aspiration of haemo-thorax. An intravenous drip was set up in all cases prior to operation, but blood was only given in the event of sudden haemorrhage or very occasionally at the end of operation if the blood loss had been unusually severe. This was seldom necessary because of the autotransfusion resulting from ligation of the Ductus.

Cases 1 to 31 were all done through the anterior approach, while 32 to 70 were carried out by the posterior approach, which gives a wider operative field, with greater accessibility of the mediastinal structures and greater control of the Ductus in the event of haemorrhage. Follow-up has also shown fewer keloid scars and less resulting chest deformity with this approach. With the patient lying on his right side, the fourth rib was resected, leaving the periosteum which allows reformation. The Ductus was identified by the characteristic thrill and the recurrent branch of the Vagus used as guide to the dissection. The Ductus was then encircled by means

of forceps working first from one side and then from the other, the most dangerous point of the dissection being posteriorly where the Ductus is frequently adherent to the bronchus.

Obliteration of the Ductus was carried out by differing methods. In the first 12 cases thick catgut, silver wire, linen thread - the ends fixed with silver clips, tape, cellophane were all used in turn to effect obliteration. Thereafter, however, it was considered sufficient to obliterate the Ductus over a reasonable length close to its Aortic end by two or three ligatures of No. 5 Chinese twist silk. Tying close to the Aorta prevents dilatation occurring on either side of the ligature, the precursor of recanalisation. The chest was closed, leaving no drainage tube in situ. On return from theatre the patient was nursed in an oxygen tent as long as needed - from a few hours to 48 hours.

During the operation itself, B.P. and Pulse readings were made at two-minute intervals, particular attention being paid to the diastolic pressure at the time of ligation, a rise being taken as evidence of satisfactory ligation of the Ductus. Further corroboration was obtained by direct auscultation of the area prior to and immediately after ligation.

OPERATION STUDIES.

1. Size, appearance of the Ductus.

Accurate measurement of the width of the Ductus is almost impossible because it varies so and may be seen to contract visibly while being handled

(an effect which may be confirmed by rise in diastolic pressure at the time). Therefore, in this series of observations measurement was not done by calipers. It was found that the average breadth of the Ductus was about 10mm. in the child and 15mm. in the adult. A width of less than 10mm. in the child was considered small, while above that was considered large. In most cases, the Ductus was rather shorter than it was wide.

In ten cases the Ductus appeared to be smaller than average. Six were unusually large. One was stomal. These findings were correlated with the clinical features of the cases in question. It was found that the six with unusually large Ductus (Cases 39, 40, 46, 58, 59, 68) had all been anticipated by reason of high pulse pressure, easily elicited positive Exercise Test, marked thrill and murmur, X-ray showing cardiac enlargement, and Electrocardiogram showing high left ventricular potentials, and some in addition showed signs of Left Ventricular Hypertrophy. Of the ten where the Ductus was smaller than normal, in four cases only (38, 42, 62, 67) did the signs suggest a rather small shunt.

Table XXIV gives the average Blood Pressure readings in cases found to have an unusually large or small Ductus.

As would be expected, the actual size of the Ductus is not the only factor of importance, and the amount of shunt would appear to be more directly related to the pressure gradient between Aorta and

Pulmonary Artery.

TABLE XXIV

Average Blood Pressure of Cases found to have

(a) unusually large Ductus,

(b) unusually small Ductus,

compared with average Blood Pressure for group

	Syst. P.	Diast. P.	Pulse Pressure
Age 5 - 9.			
average	111	52	59
large Ductus	122	54	68
small Ductus	115	52	63
Age 10 - 15.			
average	120	55	65
large Ductus	123	55	68
small Ductus	128	60	68
Age 16 and over.			
average	134	58	76
large Ductus	135	40	95
small Ductus	125	55	70

2. Observations on Pulse rate and Blood Pressure during operation.

B.P. before ligation.

The systolic pressure was noted in many cases to be considerably higher during operation than the resting level. This was due in part to the anaesthetic. About half (28 cases) showed a rise in diastolic pressure during dissection around the Ductus and in many of these cases the Ductus could be seen to contract visibly at that time.

B.P. immediately after ligation.

In all cases the diastolic pressure rose

within one minute of ligation of the Ductus, the actual amount varying from 10 to 70mm. The systolic rose in some cases also but to a less extent. This high level was maintained for only a short time, as with the re-expansion of the lung the Blood Pressure fell again temporarily. The reduced pulse pressure, however, remained.

Pulse Irregularities.

These may be in part attributable to the anaesthetic and in part to stimulation of the Vagus. Such an effect was seen in Case 66. The pulse was 160 when the Vagus was accidentally crushed with an immediate drop to 136.

Other cases showed irregularity (dropped beats, coupled rhythm) when the Ductus was handled, as Cases 31 and 52.

The immediate effect on pulse rate of tying the Ductus varied. Half showed no change. Ten showed a rise and 17 a fall. In Case 31, the rise in pulse rate was very marked for two minutes. She had had signs of very large Patent Ductus and the pulse response appeared to result from the sudden increase in the amount of available circulating blood. This case suggests the advisability of obliterating the Ductus gradually where the shunt appears very large. The more common reaction was a drop in pulse rate, which appeared in most cases to be a Vagal effect comparable to the effect in Case 66 when the Vagus was crushed. In Case 52, cardiac arrest was produced when the Ductus was ligated. This boy had

previously shown evidence of a sensitive and over-active Vagus. Autopsy showed that the superficial cardiac plexus had been included in the ligatures.

Figs. 26 to 31 illustrate the effect on Blood Pressure and Pulse rate during ligation of Patent Ductus Arteriosus.

POST-OPERATIVE COMPLICATIONS.

19 of the 70 cases had a perfect result and no post-operative complication. These all occurred below the age of 15 years, whereas above 15 years all cases surviving operation developed a haemorrhagic effusion (in two cases small). 14 of the 19 perfect cases were between 4 and 8 years. The most common complications were as follows :-

Haemothorax :	30 cases -	18	large effusion
		6	small effusion
		7	loculated
Atelectasis :	19 cases -	13	associated with effusion
Recanalisation :	7 cases -	2	later closed spontaneously
Keloid scar :	4 cases		
Recurrent Laryngeal Paralysis :	4 cases		
Phrenic Paralysis:	2 cases		
Miscellaneous :	7 cases -	Periductal haematoma	1
		Laryngitis & Bronchitis	4
		Haematuria	2
		Septicaemia	5
		Hypertension	3
		Epistaxis	6

Haemothorax.

This might occur at any age, but became increasingly frequent with age. All cases over 14 years of age developed effusion to a certain extent.

Haemothorax was usually maximal on day after operation - actual size mattered little, though the larger effusions tended to recur after aspiration as serous effusions. Loculated effusion was particularly troublesome - four in five consecutive operations - situated anteriorly close to great vessels was thought to be due to insoufflation of Penicillin powder around area of operation.

Atelectasis.

This was an important secondary effect of effusion. Even very small effusions were associated with lack of expansion of lung and frequently with Pneumothorax. Aspiration of effusion usually resulted in satisfactory re-expansion, but seven loculated effusions were all associated with prolonged incomplete expansion of lung.

Two cases required bronchoscopy.

Two cases who died with massive collapse of lung both had considerable haemothorax.

Recanalisation.

Case 2, aged 18yrs. - Ductus was ligated with two silk ligatures, no difficulty in dissection. Recanalised on 12th day with return of continuous murmur. Subsequently disappeared between one and three years after operation.

Case 5, aged 13yrs. - Ductus ligated with two silk

ligatures. Adherent to L. bronchus. Recanalised on third day with return of murmur and fall in diastolic pressure. Ductus remains patient five years after operation.

Case 6, aged 5yrs. - Ductus ligated with two silk ligatures. Difficult dissection as Ductus running parallel to Aorta and difficult to separate. Ductus recanalised 15 days after operation, with return of continuous murmur and thrill.

Case 21, aged 27yrs. - Ductus ligated with two silk ligatures. Very adherent. Extremely ill with bacterial endarteritis. Pulmonary diastolic murmur appeared within a few days of operation. Six months later Gibson Murmur had returned, with fall in diastolic pressure.

Case 38, aged 6yrs. - Ductus ligated with two silk ligatures; smaller than usual, no difficulty in dissection. Ten days after operation developed soft continuous murmur with fall in diastolic pressure and ten days later faint thrill. When seen ten months after operation, no evidence of Patent Ductus - Ductus had apparently closed spontaneously.

Case 45, aged 14yrs. - Ductus ligated with two silk ligatures, but stomal and had no length. Ligatures applied with difficulty. On 19th day developed Pulmonary diastolic murmur with continuous murmur brought out after exercise. Signs have gradually become more marked in two years following operation.

Case 46, aged 9yrs. - Ductus ligated with two silk

ligatures. Large Ductus which showed definite contraction when handled. Seventh day, recurrence of diastolic and two days later continuous murmur. During 18 months since operation, signs have become rather less.

On the whole, recanalisation appears to occur more readily in the large Ductus. It occurred in three of the first six cases in the series. Thereafter ligation was carried out close to the Aorta. Of the four other cases which recanalised - one was gravely ill with bacterial endarteritis, one was stomal and almost impossible to ligate, one was a very large Ductus, and in the fourth recanalisation was minimal and subsequently disappeared.

It is noteworthy that the development of the continuous murmur in those recanalised cases is different from the development in the young child. In the baby, the murmur may be systolic only, presumably due to the relatively higher Pulmonary pressure, whereas in the recanalising case a diastolic murmur is the earliest heard, followed quickly by a continuous murmur.

Keloid Scar.

This occurred in four cases with anterior scar. Since using posterior approach, no keloid scar has developed.

Recurrent Laryngeal Paralysis.

This occurred in four cases. In one (53) there was so much inflammatory reaction around the Ductus that it was impossible to free the nerve

completely. This case, however, had completely recovered after six months.

In three others the Nerve was isolated and held free from ligature. One recovered six months later. One was still paralysed but compensated three years later. The third was still complete and uncompensated six months after operation.

In these cases, the Nerve may have been damaged as it was handled at operation or may subsequently have been involved in tissue reaction around the ligatures.

Phrenic Paralysis.

This occurred in two cases temporarily, but in both diaphragmatic movement was free after three months.

Miscellaneous.

Periductal Haemotoma - occurred in one case three months after operation, giving rise to a large swelling, pressing on the upper lobe of Left Lung, with resultant haemoptysis. Operation was attempted to relieve this but haemorrhage occurred from large veins in the granulation tissue, and the patient died.

Haematuria occurred in one case on the sixth day after operation without other evidence of renal dysfunction.

Hypertension was also noted in a girl aged 11. Prior to ligation B.P. was 120/60, on day following 150/120, next day 130/110, thereafter gradually fell to final level 124/88. Unlike Bourne's case (1941), she showed no impairment of

renal function. Blood Urea and Urea Clearance Test remained normal.

DEATHS.

There were seven deaths.

Three occurred at operation.

Case 30, aged 32yrs. - from haemorrhage due to perforation of an infected Ductus situated more posterior than usual.

Case 70, aged 25yrs. - from cardiac arrest during control of haemorrhage from Ductus.

Case 52, aged 19yrs. - from cardiac arrest immediately following ligation of Ductus.

Three occurred within two days of operation.

Case 1, aged 19yrs. (infected Ductus) - massive collapse two days later.

Case 12, aged 29yrs. (infected Ductus) - massive collapse two days later.

Case 18, aged 5yrs. - massive collapse following day.

One occurred four months later as result of second operation for relief of periductal haematoma (Case 58, aged 5yrs.)

SUMMARY.

70 cases submitted to operation.

7 complicated by bacterial endarteritis

61 uncomplicated.

Mortality.

Total series 10%

uncomplicated 4.9%

infected cases 44%

Operation Studies.

1) Size of Ductus.

Unusually large Ductus 6 cases

Unusually small Ductus 10 cases

No close relationship between size of Ductus and estimated size of shunt by clinical methods.

One Stomal Ductus found.

2) Pulse rate and Blood Pressure during operation.

Rise in diastolic pressure noted during dissection of Ductus in many cases.

Rapid rise in diastolic pressure following ligation.

Pulse irregularities common, possibly Vagal effect.

Effect of tying Ductus (58 cases)

No change	31 cases
Rise in pulse rate	10 cases
Fall in pulse rate	17 cases
Cardiac Arrest	1 case

Post-operative Complications.

Nil	19
Haemothorax	30
Atelectasis	19
Recanalisation	7 (2 later closed)
Keloid scar	4
Rec. Laryngeal Paralysis	4(2 later recovered)
Phrenic Paralysis	2 (both recovered)
Miscellaneous	7
Periductal Haematoma	

Haematuria

Hypertension

Laryngitis and Bronchitis (2)

Septicaemia

Epistaxis

Deaths.

During operation 3 cases (2 infected)

haemorrhage 1 case

cardiac arrest 2 cases

Following operation 3 cases (2 infected)

massive collapse of lung

From late complication 1 case

Periductal haematoma

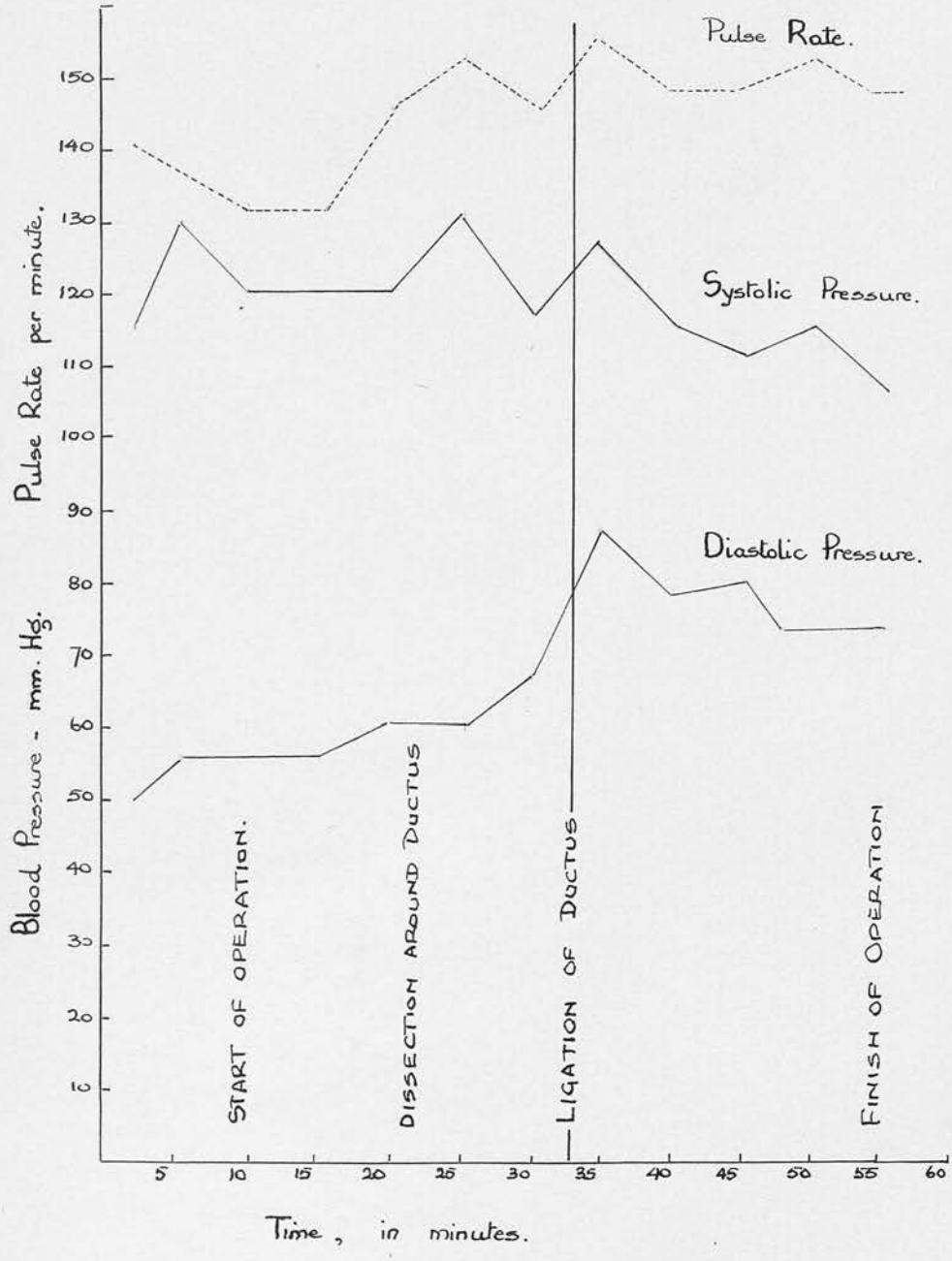


FIG. 26 Ligation of Patent Ductus Arteriosus
Case 25 : age 26
Slight rise in diastolic pressure during dissection of Ductus
Rise in diastolic pressure immediately after ligation
Little effect on systolic pressure or pulse rate

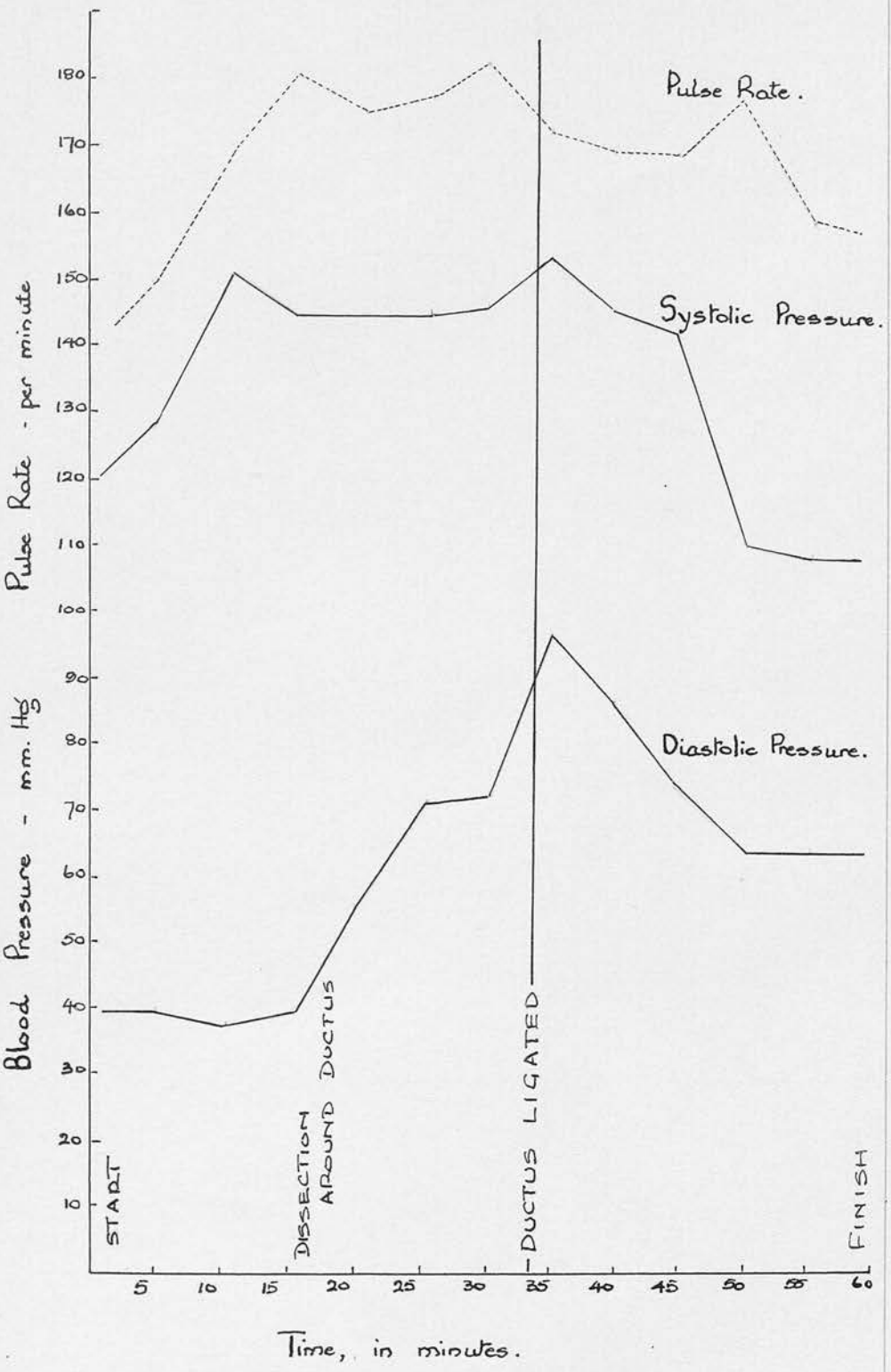


FIG. 27 Ligation of Patent Ductus Arteriosus
Case 15 : age 7
Gradual rise in diastolic pressure during dissection around Ductus, with further rise following ligation.
Little effect on systolic pressure or pulse rate

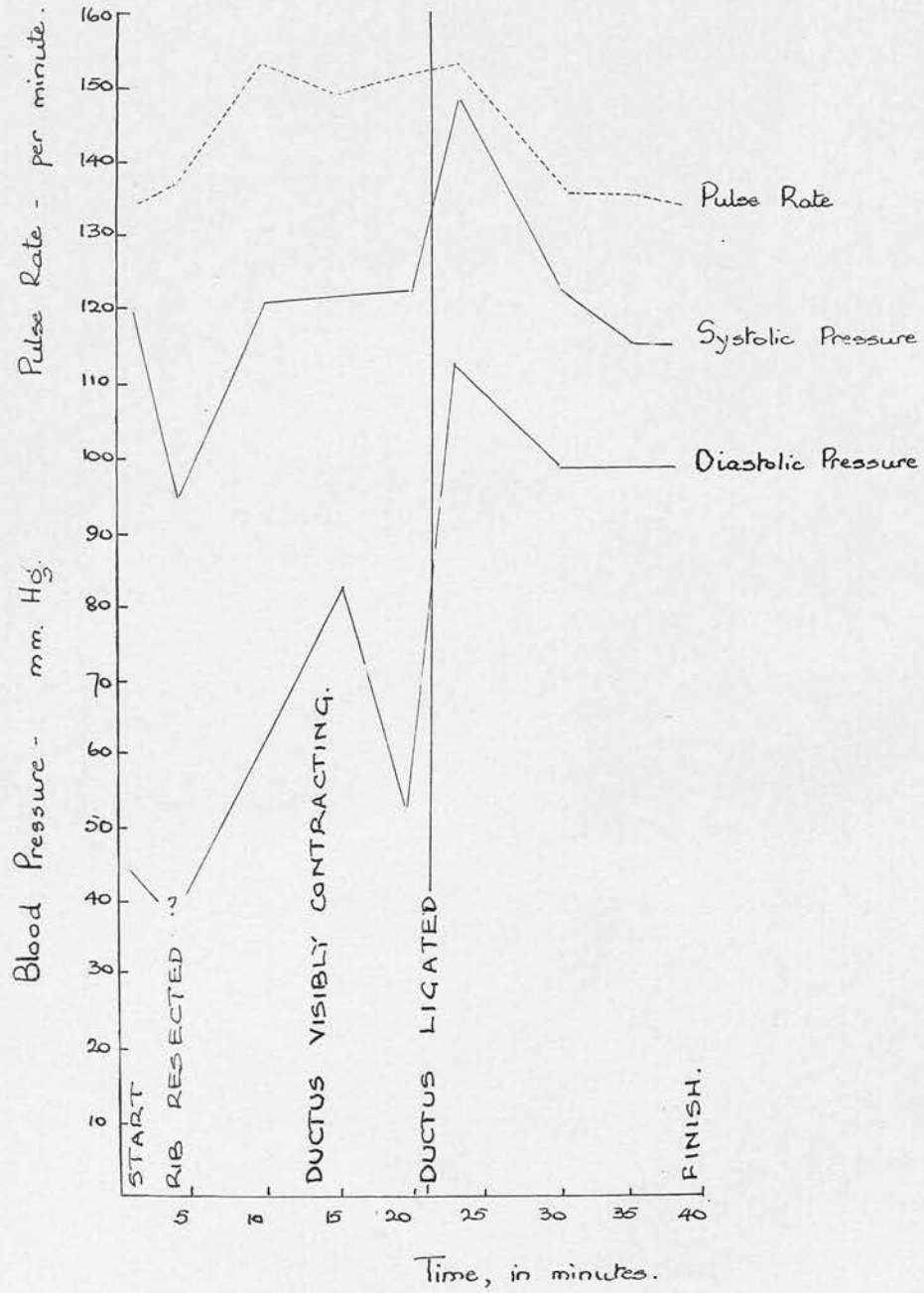


FIG. 28 Ligation of Patent Ductus Arteriosus
Case 46 : age 9
Drop in systolic pressure when rib resected
Dissection around Ductus produces visible contraction and rise in diastolic pressure
Marked rise in diastolic pressure when Ductus tied, with secondary rise in systolic pressure
No marked effect on pulse rate

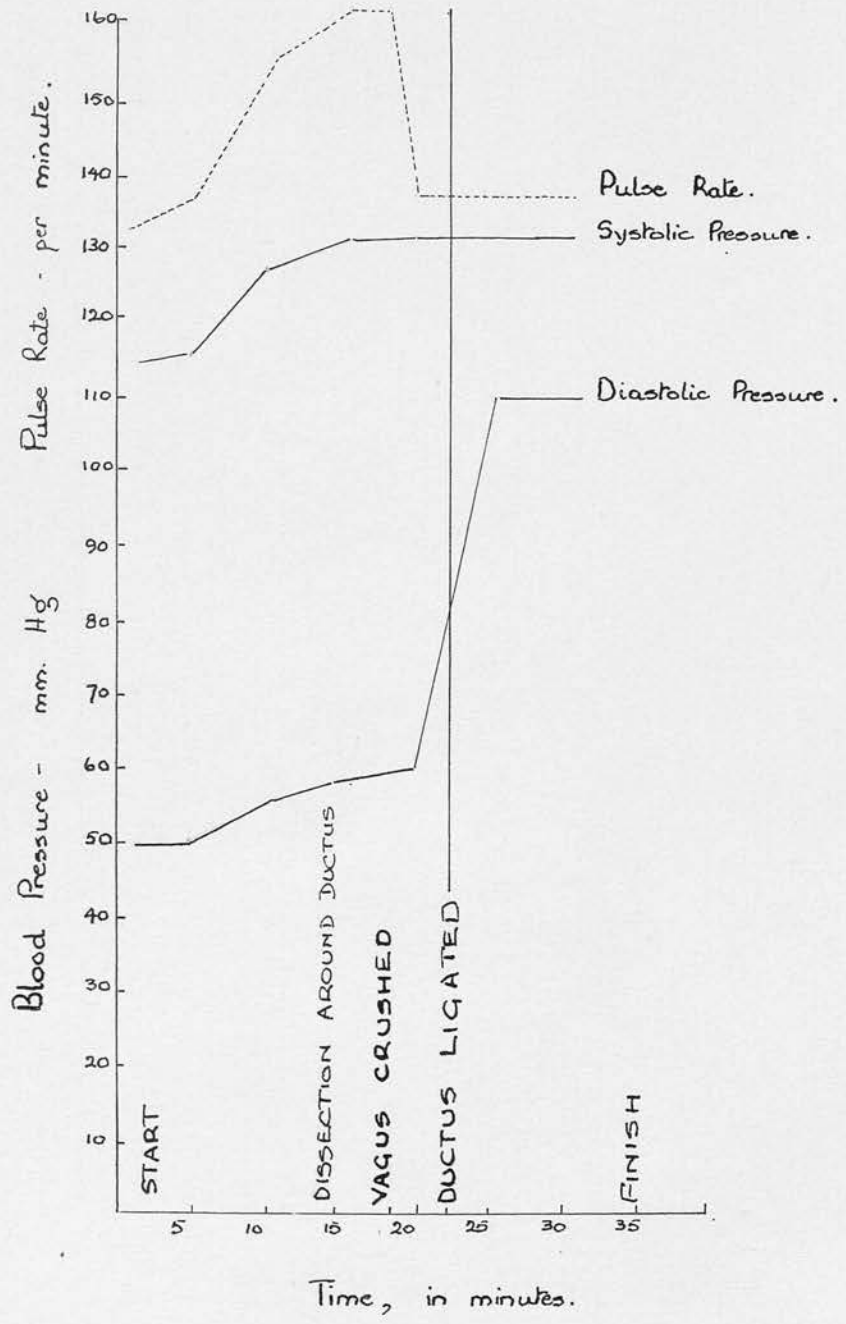


FIG. 29 Ligation of Patent Ductus Arteriosus
Case 66 : age 7
Sudden drop in pulse rate from 160 to 136 when Vagus crushed accidentally
No rise in diastolic pressure when dissection proceeding
Rise in diastolic pressure following ligation of Ductus

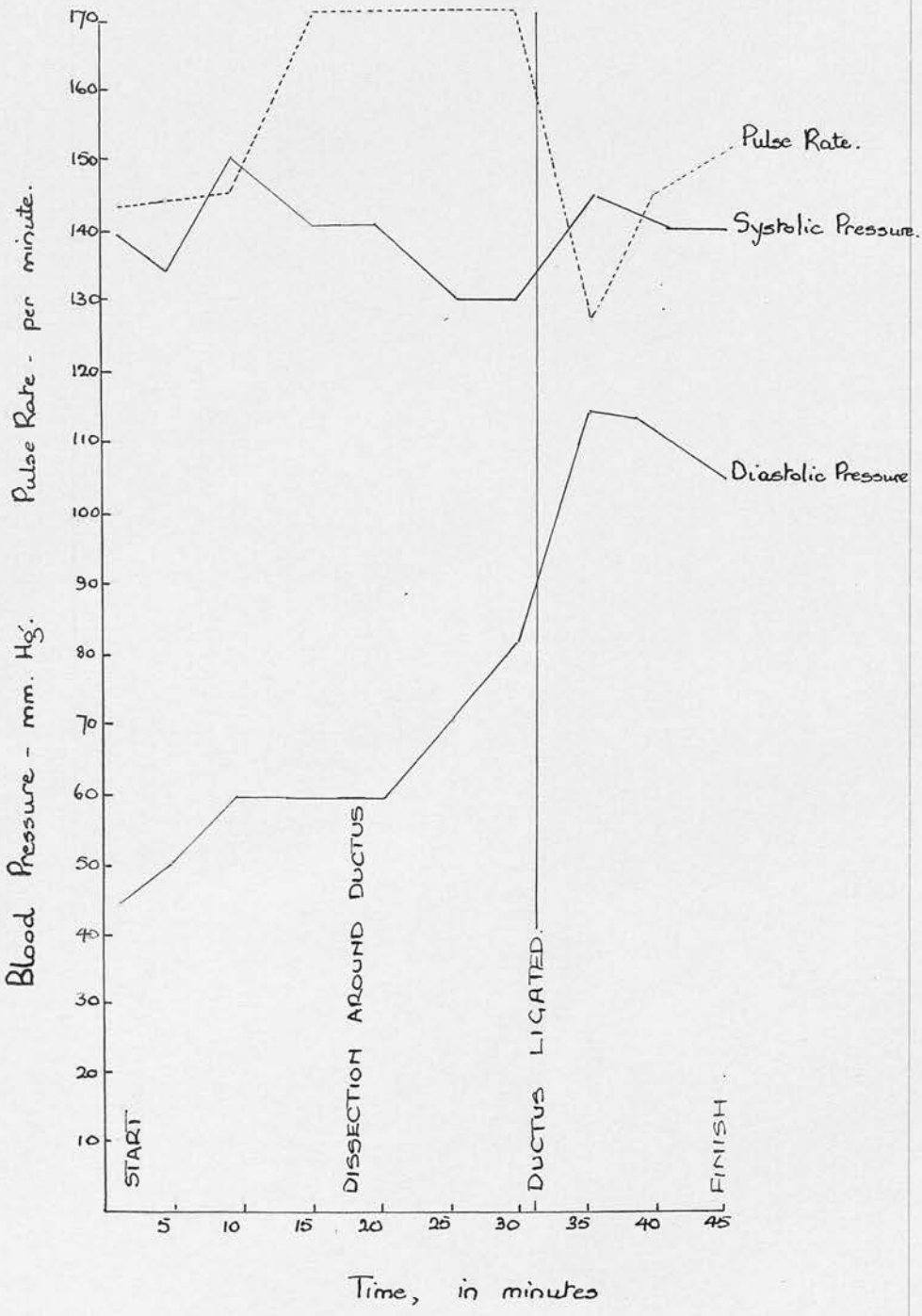


FIG. 30 Ligation of Patent Ductus Arteriosus
Case 44 : age 6
Gradual rise in diastolic pressure during dissection of Ductus, associated with marked tachycardia.
Ligation of Ductus produces rise in diastolic pressure and immediate fall in pulse rate

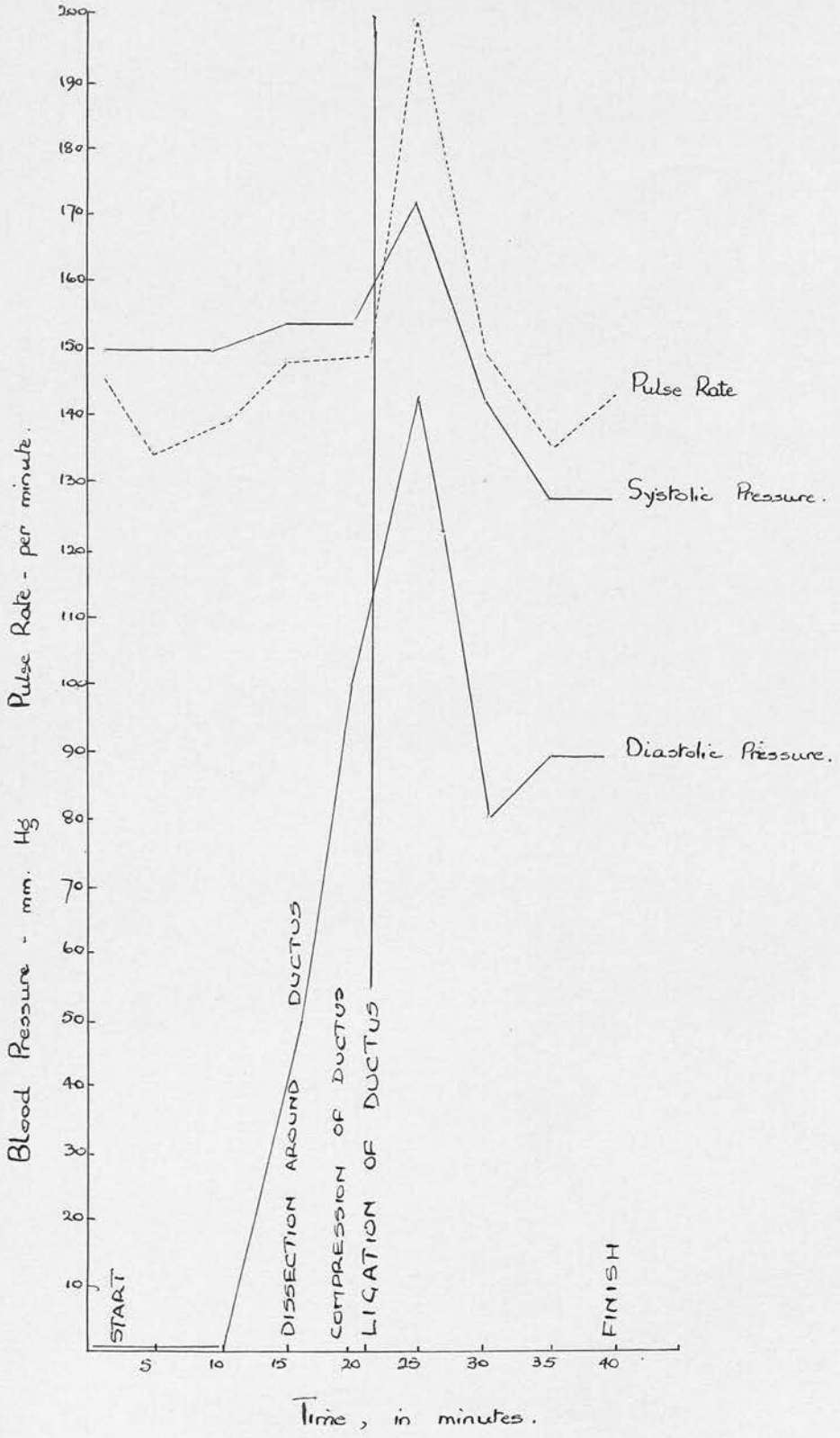


FIG. 31 Ligation of Patent Ductus Arteriosus
Case 31 : age 9
Rise in diastolic pressure as Ductus dissected
Further rise when compressed
Very marked rise in diastolic pressure (70mm.) when Ductus ligated, associated with marked tachycardia for two minutes.

FOLLOW-UP AFTER LIGATION OF PATENT DUCTUS ARTERIOSUS

Seventy cases of the preceding series were submitted to operation. Three died during operation and three within three days thereafter. The 64 surviving cases have been followed up at three to six-month intervals during the first year after operation, and thereafter annually. One case died after five months, but the others have been followed for a minimum of six months. The longest follow-up was nine years.

The method of study has been similar to that carried out before operation, and the findings are discussed under the following headings :-

Symptoms,

Clinical Features -

Nutrition

Physical Signs in Cardiovascular System (auscultatory signs and blood pressure studies)

Radiology of the heart

Electrocardiography

The cases have been divided into three groups according to age at time of ligation :-

(a)	4 to 10 years	36 cases
(b)	10 to 16 years	18 cases
(c)	16 years and older	10 cases

SYMPTOMS.

SCHOOL AGE GROUP (a) 4 to 10yrs. (36 cases)

Previous to operation, five cases in this group had no complaints. Of the remaining 31 cases the commonest complaint was tiredness (23 cases). This was a conspicuous complaint, in most dating from going to school and in many becoming more marked with the passage of years. Six complained of breathlessness, 13 of recurrent coughs and colds, five of undue pallor and two of fainting attacks.

Immediate improvement was marked in all children, and six months after operation all had shown decided improvement with the exception of one child, who had been symptom-free before and was thought to be rather more easily tired than previously. Of the other four symptom-free children two were as fit as before operation, while two had improved so much that their mothers realised in retrospect that their children had been slightly handicapped before.

The major complaint before operation was tiredness. Two months after operation there was improvement in all. Six months after operation the complaint had entirely disappeared. All were fit for a whole day at school, including two cases which had been complicated by bacterial endarteritis.

Breathlessness on exertion had also disappeared in all but four by six months. Two of these had atelectasis and one a pleural effusion with residual pleural thickening after operation. By one

year, only this latter child was still breathless, and he had cleared by two years.

Undue pallor disappeared almost immediately after operation. The change in appearance was striking - a fragile appearance being replaced by a look of robustness.

Two children subject to fainting attacks had no recurrence after operation. In one of these the faints occurred with breath-holding attacks, but after operation similar breath-holding had no effect.

Recurrent colds and coughs before operation were extremely troublesome to clear, and in many cases a quiescent interval had to be seized for ligation, but thereafter there was immediate benefit even where the lesion appeared to be bronchiectatic. The reduction in pulmonary congestion apparently allowed the natural defences to assert themselves. One child (Case 55) who had had recurrent bronchitis before operation, developed a severe pneumococcal septicaemia three months after, with severe congestive failure and acute Nephritis, but recovered after Penicillin therapy - and in 1½ years follow-up since has had no further trouble.

Two other children who had not previously been subject to colds developed chest trouble :-

1) Case 48, who developed pleural effusion (presumably tuberculous) on the right side six months after operation,
2) Case 33, who developed Primary Tuberculosis with epituberculous appearance two years after

operation.

Both children, however, made a good recovery.

Apart from the relief of symptoms as above, the Mothers all commented on the increase in drive which they noticed. The children were now much more keen to do things and took a better place at school.

Twelve in the group were followed for three years or more. Of these,

a girl of 11 was champion of her school games,

a boy of 9, who had previously been only fit for a special school for handicapped children, was playing in School Rugby Trials,

a girl of 11 had a Life-saving Certificate for swimming,

two other girls had school swimming certificates,

two were tap-dancing.

Eight were followed for four and five years, seven for six years. In no case was there any deterioration in the capacity for exercise. There was no return of symptoms in any case, and no development of bacterial endarteritis.

SCHOOL AGE GROUP (b) 10 to 16yrs. (18 cases)

Before operation, 14 of the 18 children were breathless on exertion. By six months, this complaint only remained in one - a girl of 11 who had had a troublesome loculated effusion lying anteriorly, which had delayed lung re-expansion.

Similarly, tiredness and lack of energy had disappeared in all nine cases in which it had been

present, with one exception - a girl with Stomal Ductus which recanalised.

Recurrent colds and coughs were also immediately improved. One girl of 11, who suffered from Recurrent Bronchitis and had been unfit to attend school for 1½ years, had only one cold in the first year after operation - and was able to walk two miles to and from school daily over a country road, and was taking part in school country-dancing.

One boy who had congestive heart failure before operation at the age of 13 years, had no recurrence in a follow-up period of nine years, and after five years was serving in the Regular Army. He has since been Boxing Champion for the Division and is Trainer of the Regiment Football Team.

On the whole, results were even more dramatic than in the younger school group. Of 15 followed for one year or more,
nine were playing games and taking a full part in school activities,
three were doing better at school work and one had taken a Scholarship.

By two years after operation all were completely fit, except two cases where the Ductus had recanalised - but one of these was much improved, and was playing Hockey where previously she had hardly been fit to walk to school, and had very marked increase in initiative.

Six were followed for four years, five for five and six years and one for nine years. In no

case after the initial improvement was there any deterioration in condition.

Eight have reached the stage of employment. Their occupations are as follows :-

Regular Army	1 case (5yrs. after operation)
Office work	3 cases
Shop assistant	2 cases
Biscuit factory	1 case
Message boy	1 case

All are earning their living as normal adults, with the exception of the last case - with a recanalised Ductus - an under-nourished boy not really fit to hold a heavy job, and on this account frequently changing his occupation.

ADULT GROUP 16yrs. and over (10 cases)

In this group of ten cases two had no complaint before ligation and were equally well six months after.

Three with bacterial endarteritis cured by ligation were equally well after six months.

The remaining five, whose complaint before operation was tiredness and breathlessness, were all symptom-free by six months after operation.

Six were followed for three years or more, and as in the younger groups improvement following operation was maintained, including Case 21 in whom the Ductus recanalised.

One woman (Case 42) had her first child 18

months after ligation, and in spite of very prolonged labour due to uterine inertia, showed no disability.

The occupations followed by the ten cases in this group are as follows :-

Traveller	1
Clerk or Clerkess	3
Housewife	3
Doctor	1
Nurse	1
Newsboy	1

SUMMARY.

Improvement was striking and immediate at whatever age the Ductus was ligated, and reached a maximum between six months and a year after operation. Such improvement was maintained even after many years of follow-up. Disability only remained in those cases where the operation was not completely successful, i.e., those in which the Ductus recanalised.

All were able to lead normal occupations after successful operation without disability. Some of these were strenuous, as e.g., Regular Army, Nursing, factory work.

POST-OPERATIVE CLINICAL FEATURES

NUTRITION.

It will be recalled that in the section dealing with nutrition prior to operation, it was shown that the average height and the average weight of cases of Patent Ductus Arteriosus were both statistically significantly below that of their siblings, a finding which bore out the clinical impression that these children with Patent Ductus Arteriosus were more frail and more fragile than average. Many workers including Gross (1940), Gilchrist (1945), Gross and Longino (1951), have been impressed with the remarkable improvement in physique which frequently follows ligation of the Patent Ductus. In this series, the change in physical appearance has already been mentioned. The children lose their fragile appearance quickly. In spite of large weight gains, however, comparison of the height and weight after operation shows that many remain below average even when followed for years. This present investigation was therefore undertaken to assess whether the apparent improvement after ligation was, in fact, significant.

Average height and weight before and after operation.

The 51 cases of Patent Ductus Arteriosus which were used for the statistical analysis earlier were again examined after operation and a regression curve made, based on the measurement of height at the last time of examination(H = 32.3140 + 0.1638A - H = height in inches, A = age in months).

Statistical comparison of this curve with that based on the same cases before operation and with that of their siblings shows that while the average height of the cases after operation is higher than the average pre-operative figure, this difference is not statistically significant and the average height is still below that of the siblings.

Similarly, a regression curve based on weight at last examination following ligation ($W = 47.539 - 3.1034Y + 0.4564Y^2$) shows that the average post-operative weight lies between the pre-operative figures and those of their siblings, but the rise is probably not statistically significant.

Growth Rates before and after operation.

There is, however, another method which may be used, i.e., to test whether growth rates increase significantly after operation. This is statistically more satisfactory though arithmetically more laborious. It is done by comparing, for each individual child for whom data is available, the growth rates before and after operation, and then testing whether the individual differences in growth rate when taken as a whole differ significantly from zero in the positive direction. This involves fitting a regression equation to each child of the form W or H = K+bA+cT, where W is weight, H is height, A is age, T is time after operation, K is constant, b is the estimated growth rate before operation, and c is the estimated increase in growth rate after operation.

There were 12 children with a sufficiently

long period of observation both before and after operation to make this method possible. Their average growth in height before operation was 1.92 inches per year, while the average additional increment after operation was +0.23 inches per year. The individual values of c (the estimated increase in growth rate after operation), however, varied widely, four of the twelve giving negative figures. As a result, the average value is not significantly positive at the conventional 5% point. It gives a t value of 1.21 so that the odds are about 8 to 1 against this observed increase of 0.23 inches per year in linear growth rate having occurred by chance, if there is no change after operation.

Regarding weight, the average weight gain before operation was 5lbs. per year, increasing by +1.3lbs. per year after operation. Only two of the twelve children gave a small negative value for c, so that taken as a whole the figure for post-operative increment is highly significant (t = 3.64), the odds against this being a chance effect being overwhelming.

SUMMARY.

Comparison of average height and weight of children after ligation of Patent Ductus Arteriosus with similar measurements before operation and with those of siblings shows that while the average height and weight of the post-operative cases is higher than that of the same cases before operation, it is not significantly so and they are still below that of

their siblings. These curves are shown graphically in Figs. 32 and 33.

Estimation of increase in growth rate following ligation, which is a finer test, shows that there is increase in linear growth rate (average +0.23 inches per year above the pre-operative level of 1.92 inches per year), the odds being 8 to 1 against this being a chance effect. The increase in average weight gain of 1.3lbs. per year more than the pre-operative figure of 5lbs. per year is highly significant.

There is thus evidence that following ligation there is a significant improvement in nutrition, affecting particularly weight and to a less extent height.

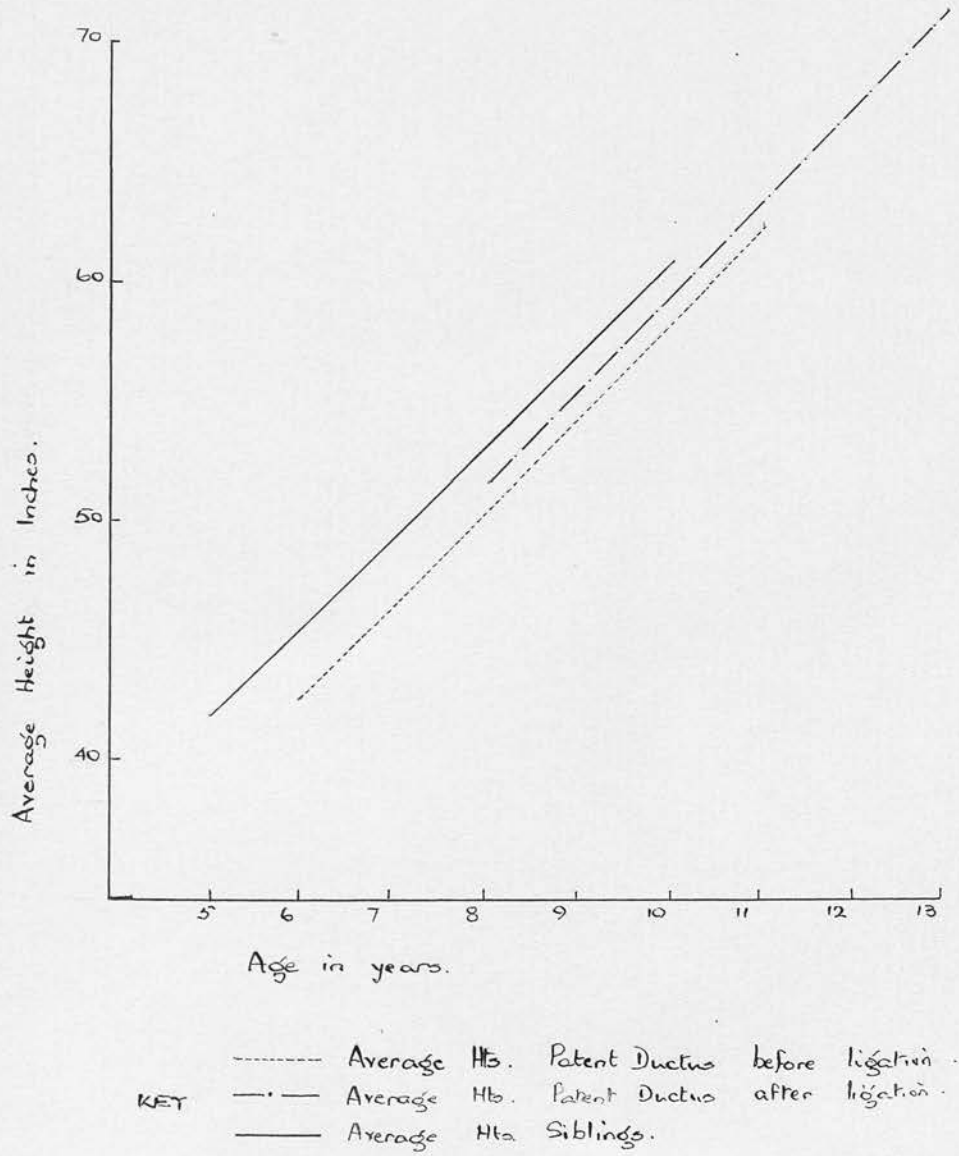


FIG. 32 Average height of 51 children following ligation of Patent Ductus Arteriosus compared with average height before and average height of siblings

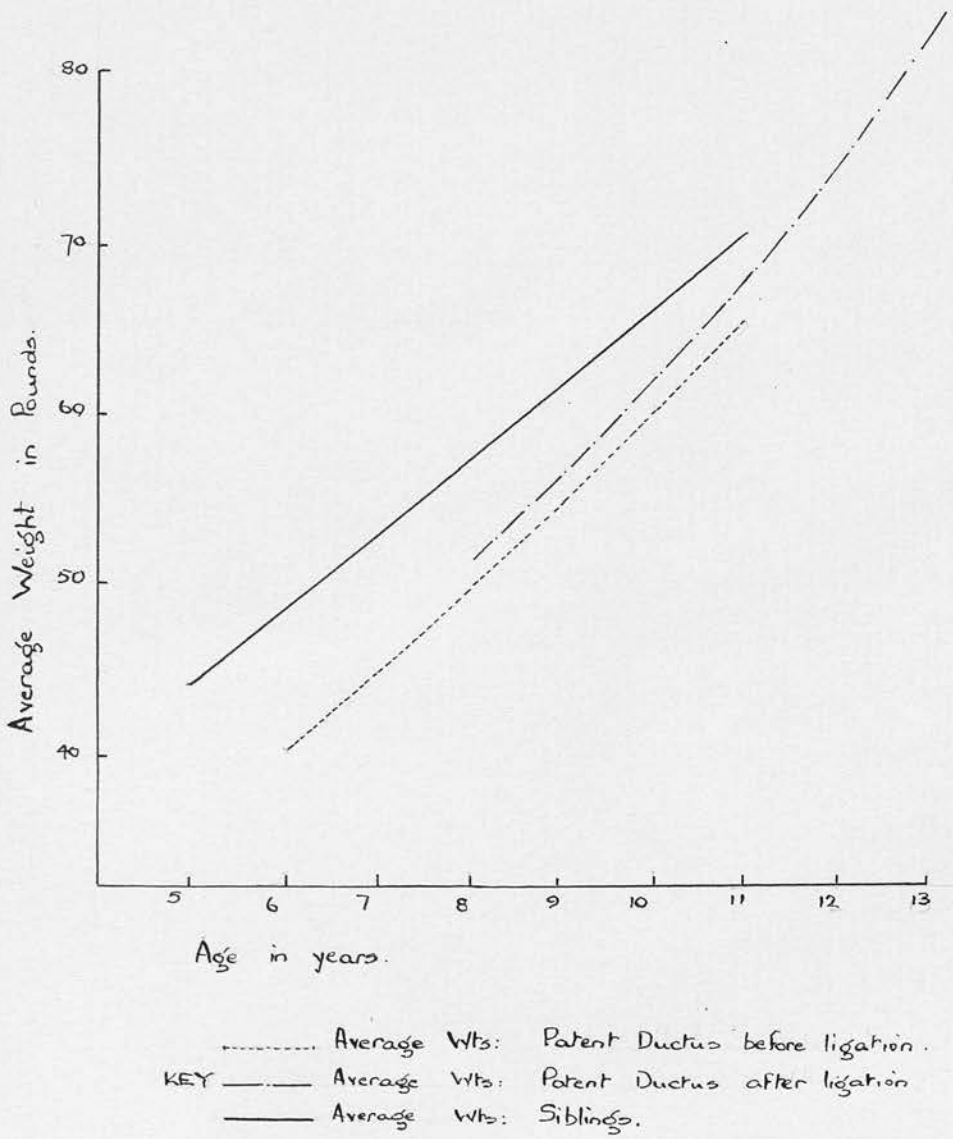


FIG. 33 Average weight of 51 children following ligation of Patent Ductus Arteriosus compared with average weight before and average weight of siblings.

POST-OPERATIVE CLINICAL FEATURES (Contd.)

CARDIOVASCULAR SYSTEM - PHYSICAL SIGNS.

Auscultatory Findings.

Except in one case occluded by a silver ring (and in which obliteration later became complete) auscultation immediately after ligation showed complete disappearance of the Gibson Murmur, thus confirming that the Ductus had been closed by ligation. Any return of the continuous murmur thereafter was taken as evidence that recanalisation had occurred.

Recanalisation has already been discussed as a post-operative complication, since it occurred in all seven within 19 days of operation. Two subsequently closed, one within six months, the other within three years, and had perfect heart sounds. In the returning murmur, the diastolic component was the first to be heard in contradistinction to the developing Gibson Murmur in the baby.

Of the other 57 cases, 38 had perfect heart sounds at the end of one year and 12 had normal sounds apart from accentuation and splitting of the second sound at the base. Four of the latter became completely normal by three years.

Seven had a residual systolic murmur either at the base or along the left margin of the Sternum. None had the characteristics of an organic murmur.

A Mitral mid-diastolic murmur was heard in 15 cases before ligation and was attributed to the increased flow through the Mitral Valve. It disappeared in all immediately after operation,

although the radiological appearance of enlarged Left Atrium persisted much longer.

Blood Pressure Studies.

These have been considered in age groups. Immediately following ligation we have already noted a rise in Diastolic Pressure of 30 and 32mm. Hg. respectively in the two school-age groups and of 24mm. Hg. in the adult. There is relatively less rise in the systolic pressure with resultant reduction in Pulse Pressure. This reduction in Pulse Pressure is maintained following operation, although the levels of Systolic and Diastolic Pressure gradually fall until the final level is reached, which is remarkably similar for all groups, as can be seen below :-

TABLE XXV

Average Blood Pressure in Age Groups following ligation of Patent Ductus Arteriosus

	Age Group	Syst.P.	Diast.P.	Pulse Pressure
Pre-operative	5-10yrs.	115	49	66
	10-16yrs.	119	54	65
	16+	115	49	66
Post-operative 1 day	5-10yrs.	131	89	42
	10-16yrs.	130	92	38
	16+	127	88	39
1 week	5-10yrs.	122	83	39
	10-16yrs.	118	84	34
	16+	125	81	44
1 month	5-10yrs.	116	73	43
	10-16yrs.	113	75	38
	16+	119	78	41

Examination of the foregoing table shows that the Pulse Pressure on the first day after operation closely approximates to the final reading. This applies to all age groups and it is of interest to note how close the final Blood Pressure readings are in all groups. Systolic and Diastolic Pressure fall gradually, until by one month after operation normal levels of pressure are reached.

If those cases in which the Pulse Pressure originally is higher than average are similarly considered, it can be seen that the initial rise in Diastolic Pressure is correspondingly higher and the ultimate figures reached the same, whatever the original Blood Pressure readings have been.

TABLE XXVI

Average Blood Pressure in Age Groups of cases with original Pulse Pressure above average, following ligation of Patent Ductus Arteriosus.

	Age Group	Syst.P.	Diast.P.	Pulse Pressure
Pre-operative	5-10yrs.	122	44	78
	10-16yrs.	125	50	75
	16+	144	51	93
Post-operative 1 day	5-10yrs.	135	98	37
	10-16yrs.	137	96	41
	16+	126	84	42
1 week	5-10yrs.	129	96	33
	10-16yrs.	123	86	37
	16+	124	81	43
1 month	5-10yrs.	119	79	40
	10-16yrs.	116	78	38
	16+	121	81	40

There is thus little difference in the final figures between the groups as a whole and those cases within the groups which had originally Pulse Pressure above average.

Exercise Test was carried out in all cases after operation with the same technique as before operation. Of five cases with recanalisation of the Ductus three showed a typical fall in diastolic pressure, while two with minimal signs were normal.

Of the other cases, two (29 and 47) continued to show a steep fall in diastolic pressure for a few months after operation, which subsequently disappeared. There were no other signs of recanalisation present, and this finding is thus difficult to explain. Of the remainder, 10 showed no change after exercise, 10 a fall in diastolic pressure up to 10mm., and the rest a rise in diastolic pressure of 5 to 15mm. Exercise test was thus essentially normal following satisfactory ligation.

SUMMARY.

Auscultatory Findings - 64 cases

Perfect heart sounds	44 cases
Accentuated second Pulmonary sound (none of these followed more than 2yrs.)	8 cases
Functional Systolic Murmur	7 cases
Recanalisation	5 cases
Mitral mid-diastolic Murmur	Nil

Blood Pressure.

Immediate reduction of Pulse Pressure to normal levels on day following ligation, associated with raised Systolic and Diastolic Pressures.

Gradual fall in Systolic and Diastolic Pressures to normal levels during the first month, with little change in Pulse Pressure.

Final Blood Pressure readings are similar for all groups. There is no difference in final readings within the groups between cases originally showing high Pulse Pressure and those with average Pulse Pressure.

Exercise Test was normal following operation in the satisfactorily occluded cases, with the exception of two who continued to show a steep fall in diastolic pressure during the first year after operation, but who subsequently showed a normal reaction.

Three out of five in which the Ductus recanalised showed positive tests.

POST-OPERATIVE CLINICAL FEATURES

CARDIOVASCULAR SYSTEM - RADIOLOGICAL FEATURES.

SCHOOL AGE GROUP (a) 4 to 10yrs. (36 cases)

35 of this group were submitted to operation and 34 survived. Two children from the younger group who had ligation carried out at 4 years have also been included in this post-operative analysis, making a total of 36 cases. Radiological study of the post-operative case has been carried out as before operation.

Cardiac Size.

Reduction in cardiac size following operation was very striking in this group. In 15 cases it was true reduction, in the others it was relative, the child growing and the heart size remaining stationary. Prior to operation 71.4% of the group had a cardiac area above normal, i.e., more than +10% above the predicted area, but one year after ligation only 28% fell above normal limits.

Table XXVII shows the gradual fall in the percentage of cases in which the cardiac area was above normal in five years of post-operative follow-up.

The reduction in size occurred in large hearts as well as in smaller. Some which were within normal limits before operation showed further reduction.

Detail of cardiac size before and after operation is shown in Table XXVIII.

TABLE XXVII

Cases with cardiac area above normal before and after operation - School age group (a)

	Total No. of cases	No. above normal	% above normal
Before ligation			
Group as a whole	46	34	72
Surviving operation	35	25	71.4
After ligation			
1yr.	32	9	28
2yrs.	30	6	20
3yrs.	9	2	22
4yrs.	6	1	16.6
5yrs.	2	1	

TABLE XXVIII

Cardiac Size - Frontal Cardiac Area - before and after operation - School age group (a)

	Cardiac area - % above or below "normal"								
No. of cases	-10 to -1	0	+1 to +10	+11 to +20	+21 to +30	+31 to +40	+41 to +50	+51 to +60	+61 to +70
Before operation 35	2	1	7	14	3	4	3	0	1
After operation									
1yr. 32	6	7	10	8	0	1	0	0	0
2yrs. 20	4	3	7	4	2	0	0	0	0
3yrs. 9	1	0	6	2	0	0	0	0	0
4yrs. 8	3	0	5	0	0	0	0	0	0
5yrs. 6	2	0	3	1	0	0	0	0	0
6yrs. 2	1	0	0	1	0	0	0	0	0

The gradual reduction in cardiac size is further shown by study of the average cardiac area for the group in the six years of follow-up.

Average cardiac area	before operation	+21.1%
Average cardiac area	one year after	+7.6%
	two years after	+6.2%
	three years after	+2.2%
	four years after	+1.0%
	five years after	+4.5%
	six years after	+8.0%

The apparent increase in cardiac area at five and six years' follow-up is due to the small number of cases, which includes one boy of very stocky build in whom cardiac area appears to have increased. It may be that predicted cardiac area for this type of build is too low.

Of the 25 cases showing generalised cardiac enlargement before operation, the Left Ventricle was prominent in 12 and the Right Ventricle in six. Disappearance of Left Ventricular enlargement ran closely parallel to reduction in cardiac size. One year after operation there was some Left Ventricular enlargement still present in two cases (7 and 11), but this had entirely disappeared by three years. Right-sided enlargement similarly disappeared with one exception (Case 15), in whom it was still present after four years, but in this case the thorax was of unusual shape, being extremely long and narrow and this may have been responsible for the abnormal shape.

Great Vessels.

Before operation, enlargement of the Pulmonary Artery was a constant feature, being shown in some degree by all. Following ligation, there was some immediate reduction in the size of the Pulmonary Artery, but in all but one (Case 62) there was some residual enlargement of Pulmonary Artery which persisted up to five and six years after operation.

Case 62 was remarkable in that the Pulmonary Artery had returned to normal one year after operation (Fig. 36).

Case 39, with infected Ductus, developed an aneurysm of the Pulmonary Artery during her illness. Following ligation there was immediate reduction in size, and further follow-up over 2½ years has shown further return towards normality (Figs. 70 - 73).

Case 46 developed a bulge in the region of the Left Pulmonary Artery one year after ligation. In this case the Ductus has partially recanalised and this shadow, which is pulsatile, would appear to be in region of the pulmonary end of the Ductus. 18 months after operation it was showing signs of calcification (Figs. 59 - 61).

No change was noted in the contour of the Aorta following operation.

Hilar Vessels and Lung Fields.

There was immediate reduction in pulmonary congestion in all cases. This was reflected in the low incidence of pulmonary infection following

operation (Case 36 - Fig. 37).

Left Atrium.

Definite enlargement of the Left Atrium was present in six cases prior to operation, associated with a mitral mid-diastolic murmur. Following operation the murmur disappeared, but radiological evidence of Left Atrial enlargement had persisted in four cases when last seen two years after operation. In one, enlargement had gone 11 months after operation. The sixth child died five months after ligation.

Screen Examination.

Five cases continued to show brisk pulsation in the great vessels up to two and three years, but the appearances could have been attributed to excitement and no significance was attached to this finding. Case 6 and Case 46 both recanalised but the brisk pulsation gradually lessened, and two years after pulsation was within normal limits, although signs of Patent Ductus persisted. Screen examination is thus not helpful where recanalisation is in doubt.

SCHOOL AGE GROUP (b) 10 to 16yrs. (18 cases)

Cardiac Size.

Reduction in cardiac size following operation was very similar to the younger group. The average cardiac area before ligation was +21.8% and one year later was +6.8%, with a slight gradual fall thereafter as follows :-

Average cardiac area before operation +21.8%
one year after operation +6.8%
two years after operation +5.2%
three years after +3.8%
four years after +5.6%
five to eight yrs. after -5.3%

The reduction in cardiac area, however, in the first year was rather less uniform than in the younger group, 67% being above normal before operation and 40% still above normal after one year (although the average had dropped considerably). However, after two years only 20% fell above normal, as is shown in Table XXIX:-

TABLE XXIX

Cases with cardiac area above normal before and after operation - School age group (b)

	Total No. of cases	No. above normal	% above normal
Before ligation			
Group as a whole	21	14	67%
Surviving operation	18	12	67%
After ligation			
1yr.	15	6	40%
2yrs.	10	2	20%
3yrs.	7	2	28.5%
4yrs.	6	1	16.6%
5-8yrs.	2	0	0

Table XXX gives detail of cardiac size before and after operation, and further illustrates the gradual return to normal size after ligation.

TABLE XXX

Cardiac Size - Frontal Cardiac Area - before and after operation - School age group (b)

No. of cases	Cardiac area - % above or below "normal"							
	-15 to -1	0	+1 to +10	+11 to +20	+21 to +30	+31 to +40	+41 to +50	+51 to +60
Before operation 18	2	0	4	5	2	2	1	2
After operation								
1yr. 15	5	0	4	4	1	1	0	0
2yrs. 10	3	2	3	1	1	0	0	0
3yrs. 7	1	1	3	2	0	0	0	0
4yrs. 6	0	1	4	1	0	0	0	0
5-8yrs. 2	1	0	1	0	0	0	0	0

True reduction in cardiac size occurred in 12 of the 18 cases; in the others the reduction was relative, due to the increased size of the child. Three cases followed for five years or more showed clearly that reduction in heart size continues for years after ligation.

Case 17 - ligated at 11yrs.

Moderately enlarged heart, Cardiac Area +40%

Cardiothoracic Ratio 53.5

Showed steady reduction in both measurements.

Cardiac Area +20%,+18%,+15%.+10%,+5% (annual figures)

C.T.Ratio 47.7 46.5 46.2 46.0 45.2 do.

Case 4 - ligated at 13yrs.

Slightly enlarged heart, Cardiac Area +22%

Cardiothoracic Ratio 48.7

Cardiac Area -12%, 0, 0, 0, +2%, -6% (annual figures)

C.T.Ratio 43.2 43.1 44 44 44.6 42.5 do.

Case 13 - ligated at 11yrs.

Heart within normal limits, Cardiac Area +5%

C.T. Ratio 42.7

Cardiac Area +8%, +6%, 0, 0, 0, -15% after six yrs.

C. T. Ratio 43.9 43 42 41 39.9 38 " " "

Great Vessels.

In some cases there was marked reduction in size of Pulmonary Artery immediately after operation, but in none did the size of the Pulmonary Artery become completely normal. Six cases followed from four to eight years still showed slight enlargement or fullness of the Pulmonary Artery segment. Whether this is due to residual enlargement of the Pulmonary Artery or a result of operation is not possible to say. Some are associated with scoliosis. In these six aforementioned cases, it was the only remaining abnormality.

Left Atrium.

Slight enlargement of the Left Atrium disappeared immediately following successful ligation. Of the two cases showing definite atrial enlargement, in one the enlargement has gone while in the other the Ductus has recanalised and the Left Atrium remains enlarged.

Screen Examination.

In all successful cases screening revealed a quiet heart with no abnormal pulsation and no hilar dance. Increased pulsation over Left Ventricle and great vessels remained, however, in two cases which recanalised.

Case 45 was instructive, as she demonstrated clearly the reversibility of the radiological signs (Figs. 54 - 55). She originally showed evidence, both clinically and radiologically, of a very large Ductus - with large heart, large Pulmonary Artery, enlarged hilar shadows with hilar dance and marked enlargement of Left Atrium.

She had a Stomal Ductus ligated with difficulty, and this subsequently recanalised.

Five weeks after operation, when signs of recanalisation were minimal, the heart size was considerably reduced, as were the hilar shadows. There was no hilar dance. The Left Atrium was no longer enlarged and screen examination showed pulsation within normal limits.

Four months after ligation, signs were more marked. Radiologically there was increased pulsation and the Left Atrium slightly enlarged.

Two years later, signs of recanalisation had increased and were almost as marked as before operation. The heart size had increased. Hilar dance had reappeared. The Left Atrium was again definitely enlarged and there was marked increase in pulsation on screen examination.

ADULT GROUP 16yrs. and more (10 cases)

Heart Size.

In this group the average cardiac area before operation was +22.4%, and there was a reduction in area to +11% in the year following ligation.

The numbers followed thereafter are small and one of them has recanalised. Three cases seen three years after operation had an average cardiac area of +13%. These three cases had had cardiac area a little above the average for the group before ligation (+24%). It is thus not possible to generalise, but examination of individual cases followed for several years suggests that gradual decrease in cardiac size does occur in this group as in the younger groups.

Case 8 - before ligation had cardiac area +23%, six months after, it was +10%; three years later +10%; six years later +4%.

Case 20 - before ligation had cardiac area +19%, six months later +7%; two years later +8%; three years later +4%.

Before operation, seven of the ten cases had cardiac area above normal - six months later only two, and one of these had recanalised.

Great Vessels.

Pulmonary Artery enlargement decreased in all, but only in one (Case 3) did it reach normal size. This was three years after operation.

Hilar Vessels and Lung Fields.

As in the younger cases, congestive changes cleared after operation - but on the whole they had been less marked before operation than in the children.

Left Atrium.

Enlargement of Left Atrium was only seen in one case prior to operation, and was still present six months later.

Screen Examination.

Pulsation in the great vessels and Left Ventricle was within normal limits in all cases, with the exception of Case 21 in which the Ductus had recanalised. Hilar dance was not seen in any before operation, and was not present after operation.

SUMMARY.

There is immediate reduction in cardiac size in practically all cases within six months of ligation regardless of age at the time of ligation. In 40 to 50% the reduction in size is a true one as measured by the transverse diameter of the heart, while in the remainder the reduction is relative, the heart growing less rapidly than the body in general. In the first six months to a year the reduction in size is very marked, thus :-

TABLE XXXI

Cardiac Area before and after ligation of Patent Ductus Arteriosus.

	Cardiac Area - % above or below "normal"	
Age at Ligation	Before Ligation	1yr. after Ligation
4-10yrs.	+21.1%	+7.6%
10-16yrs.	+22.4%	+6.8%
16yrs. and over	+22.4%	+11.0%

There is thereafter a steady though slower reduction in size. Five years after ligation, only one of six cases followed in each of the school-age groups was above normal. In the adult group only one case was followed this length of time and fell

within normal limits.

Pulmonary Artery enlargement became less, but persisted in slight degree in practically all cases (two of 64 returned to normal). The lung fields, on the other hand, showed immediate reduction in vascularity. This was quite noticeable even in cases where the degree of vascularity prior to operation had been within normal limits.

Left Atrial enlargement disappears slowly, and was still present to a lesser degree in most cases after two years.

The brisk pulsation of the Patent Ductus on screen examination is at all times difficult to distinguish from excitement. In eight cases brisk pulsation persisted. In three there were other signs of recanalisation. In two others where the Ductus had recanalised pulsation was within normal limits. On the whole it was a less reliable sign of satisfactory ligation. Only one case, which had recanalised, showed hilar dance after operation.

1)

2)

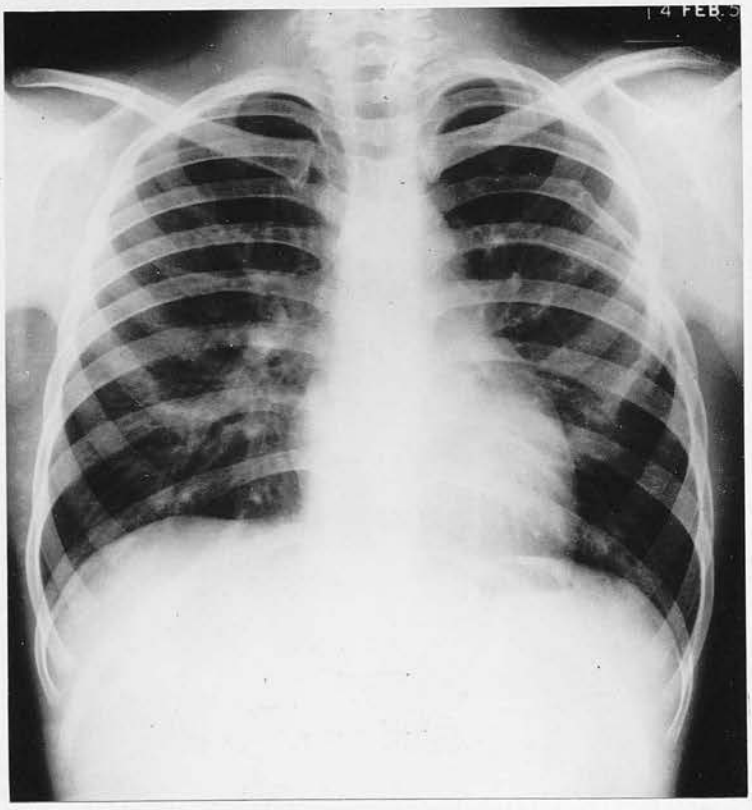
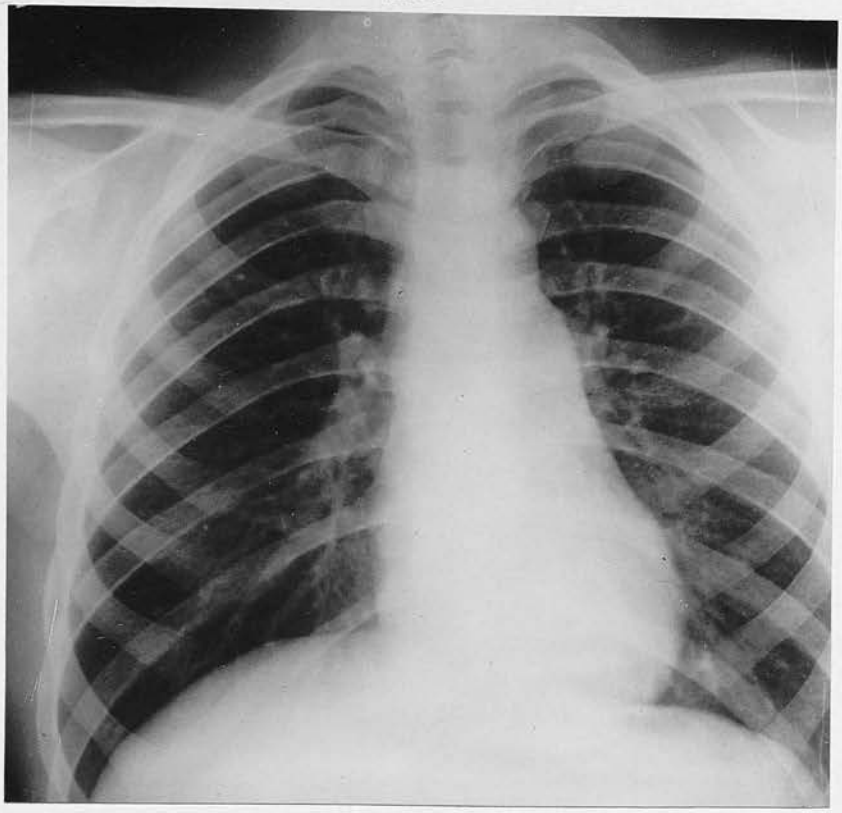


FIG. 34 Radiograph of Case 61. True reduction in cardiac size following ligation of Patent Ductus Arteriosus at 11yrs.
1) P.A. before ligation - C.A.+45% T.D.H 12.7cm.
2) P.A. 1yr. after ligation - C.A.+10% T.D.H. 11cm.
Pulmonary Artery remains prominent
Reduction in vascularity of lung fields
Resected rib regrown

1)



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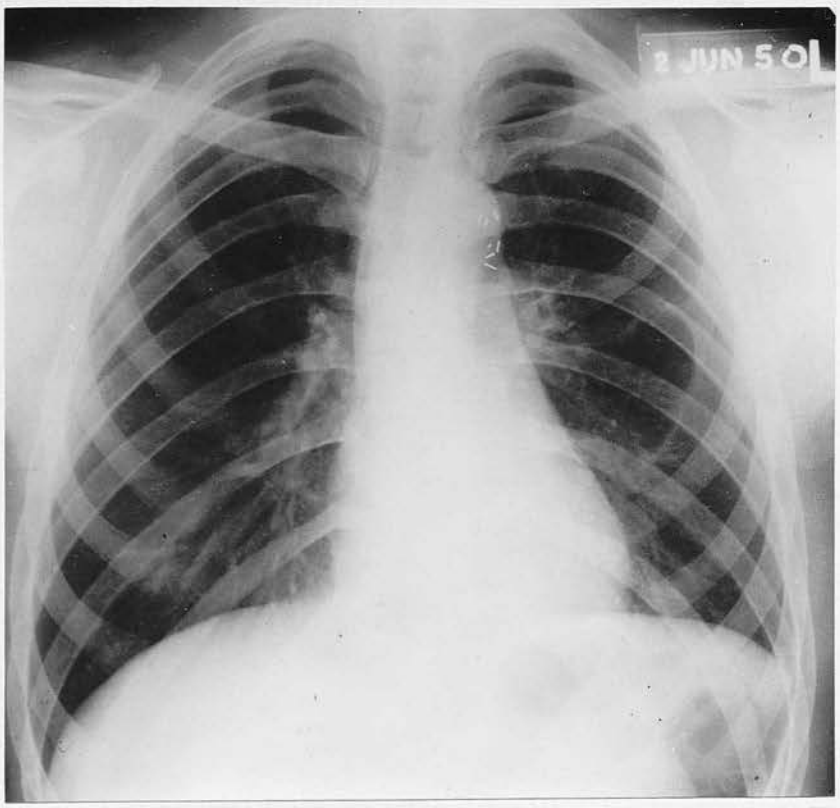
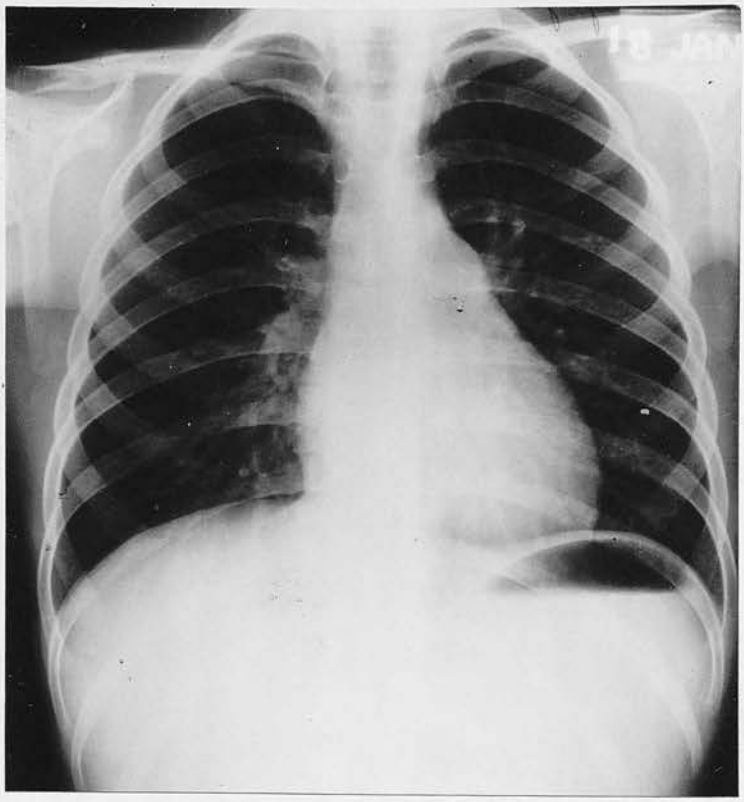


FIG. 35 Radiograph of Case 8. True reduction in cardiac size following ligation of Patent Ductus Arteriosus at 18yrs.
1) P.A. before ligation - C.A. +23%
2) P.A. 6yrs. after ligation- C.A. +4%
Reduction in size of Pulmonary Artery
Silver clips at site of operation
Resected rib not regrown satisfactorily

1)



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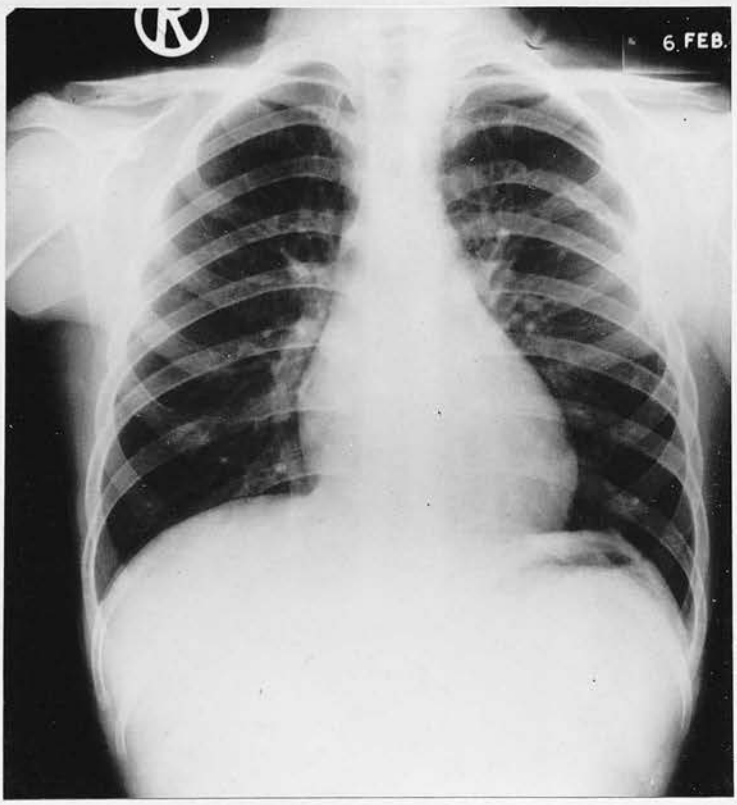
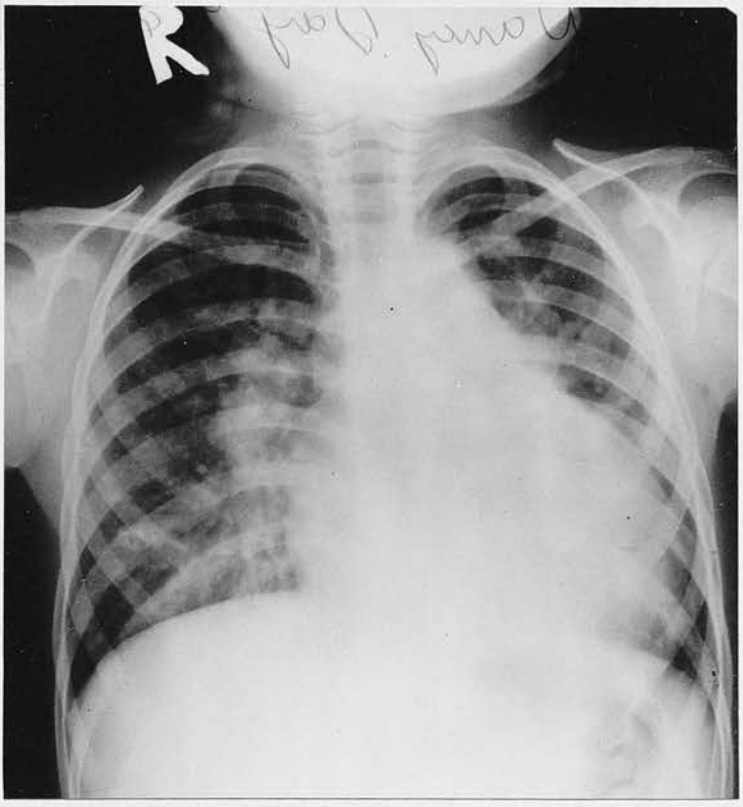


FIG. 36 Radiograph of Case 62. Marked reduction in size of Pulmonary Artery following ligation of Patent Ductus Arteriosus at 7yrs.

1) P.A. before ligation - C.A. +12%
2) P.A. lyr. after ligation - C.A. +12%
Little change in cardiac size
Pulmonary Artery within normal limits after lyr.
Resected rib regrown

1)



2)

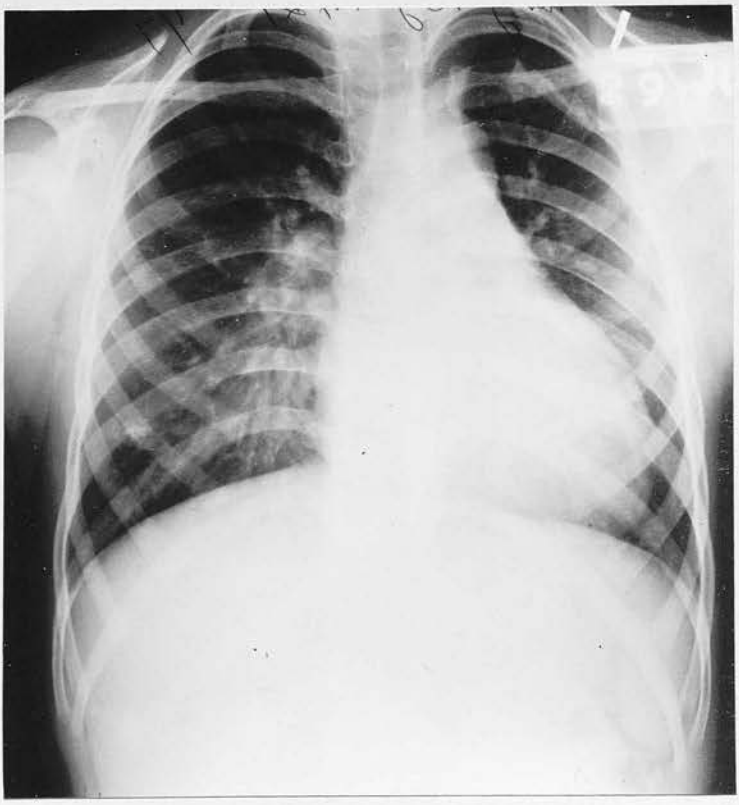
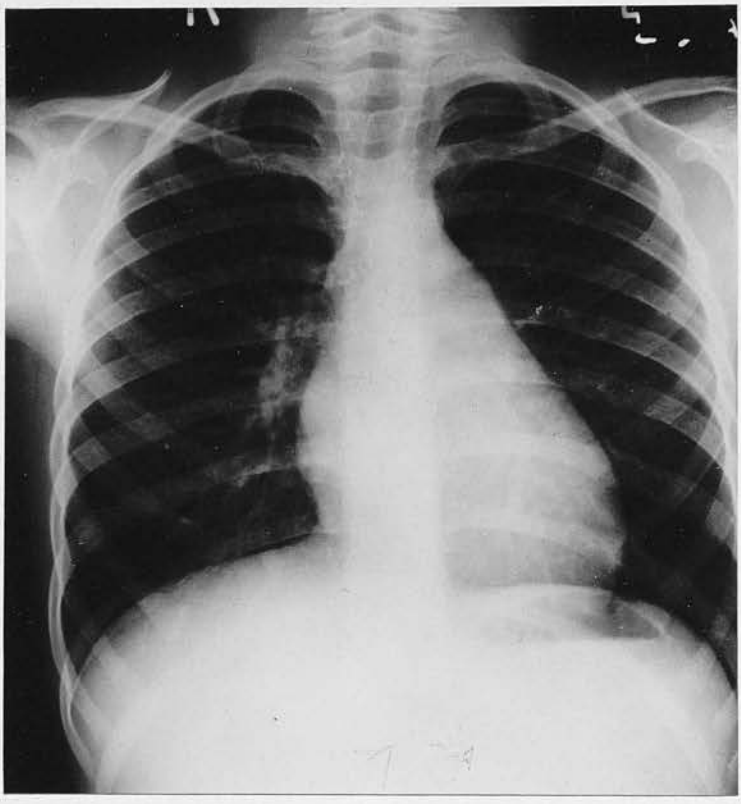


FIG. 37 Radiograph of Case 36. Reduction in cardiac size and marked reduction in pulmonary vascularity following ligation of Patent Ductus at 5yrs.
1) P.A. before ligation C.T.R. 57.5
2) P.A. lyr. after ligation C.T.R. 53.4
Reduction in C.T.R. from 57.5 to 53.4
Reduction in size of Pulmonary Artery and branches

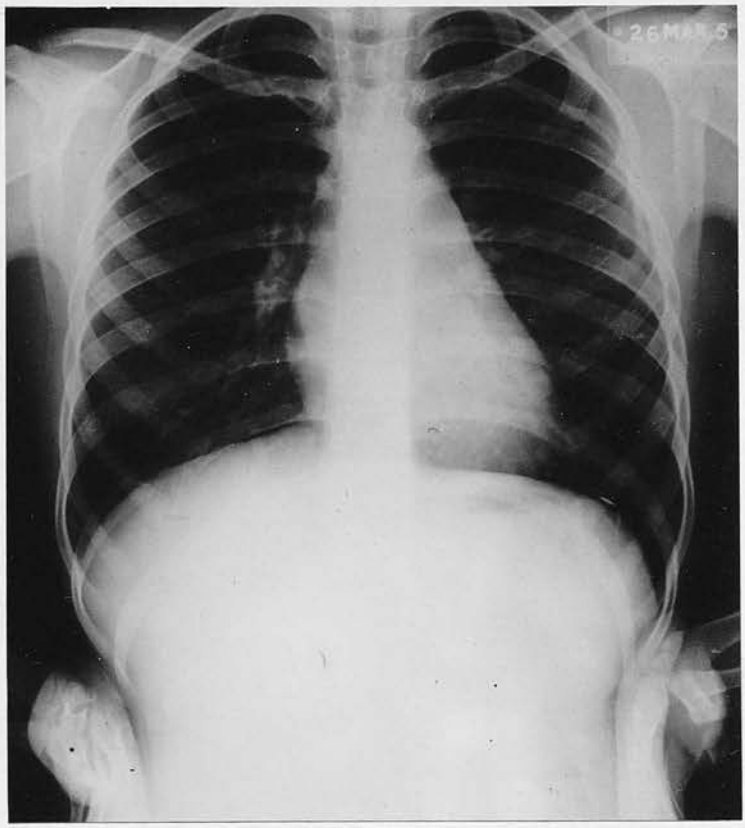
1)



2)

FIG. 38A Radiograph of Case 51. Persistence of Left Atrial enlargement 1yr. after ligation of Patent Ductus Arteriosus.
1) P.A. 2) R.A.O. before ligation.
Generalised cardiac enlargement (+20%) with unusual degree of Left Atrial enlargement

1)



2)

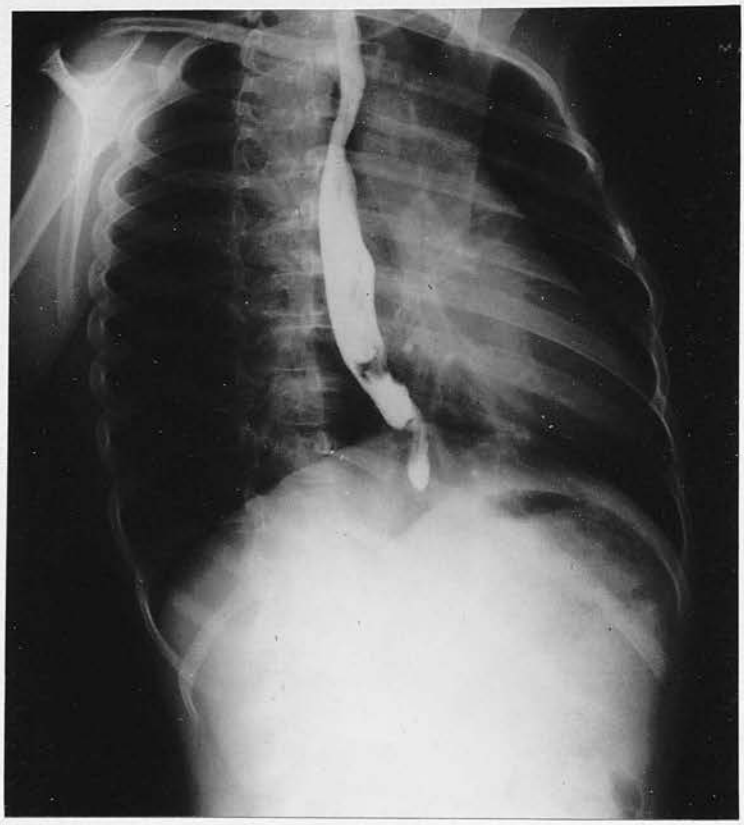


FIG. 38B Radiograph of Case 51. Persistence of Left Atrial enlargement 1yr. after ligation of Patent Ductus Arteriosus.
1) P.A. 2) R.A.O. 1yr. after ligation, at 8yrs. Reduction in cardiac size from +20% to +0%, but Left Atrial enlargement persists.

POST-OPERATIVE CLINICAL FEATURES (Contd.)

CARDIOVASCULAR SYSTEM - ELECTROCARDIOGRAPHY.

Full sets (12 leads) of Unipolar Electrocardiograms have been made in 57 cases after operation. In 30 of these, pre-operative unipolar electrocardiograms are available for comparison.

It will be recalled that the electrocardiographic picture before operation was as follows :-

Tachycardia was a feature at all ages.

Normal Rhythm was the rule, apart from the older cases where Auricular Fibrillation was seen in four.

There was a gradual lengthening of the PR interval (average in adult group being 0.18 sec.).

The position of the heart in the younger groups was mainly vertical, but in the adult group almost equal numbers were horizontal.

High voltage in Precordial Leads with tall R in V5 and deep S in V1 was frequent (64-87%), with the highest incidence in the school-age groups.

ST.T changes of Left Ventricular Hypertrophy were seen in Precordial Leads, Unipolar Limb Leads and Standard Leads in increasing frequency according to age - one case under 5yrs., seven (38%) above 16yrs.

Deep Q waves in the Left Precordial Leads and notched T waves in V2 to V4 were also a feature.

The chief interest in this series has been the follow-up of the Unipolar Electrocardiograms after operation, although since they have only been made in this series since 1948, of necessity those with

pre-operative Unipolar Electrocardiograms have been followed for less than two to three years.

SCHOOL AGE GROUP (a) 5 to 10yrs.

19 cases in this group had unipolar Electrocardiograms before and after operation. Before ligation, four were normal. 15 showed high voltage including two who showed changes of Left Ventricular Hypertrophy in addition. In a follow-up of up to two years after operation, voltage has been reduced in all but one, although 10 still remain high. Nine are now normal. The reduction in voltage was particularly noticeable in the four with the highest voltage before operation, as follows :-

	R in V5 + S in V1 before operation.	R in V5 + S in V1 after operation	
1.	109mm.	50mm.	(2yrs.follow-up)
2.	110	55	(1yr. ")
3.	108	47	(6months ")
4.	75	45	(1yr. ")

In the two cases showing minimal signs of Left Ventricular Hypertrophy (ST depression in Left Precordial Leads), there were no residual signs after six months.

15 other cases with no pre-operative unipolar leads were also followed. None showed changes of Left Ventricular Hypertrophy.

Six followed 2yrs. - five high voltage, one normal

Three followed 3yrs. - two high voltage, one normal

One followed 4yrs. - high voltage

Four followed 5yrs. - two high voltage, two normal

One followed 6yrs. - normal

Of the total of 34 cases in this group, 20 continue to show high voltage, 14 are within normal limits. None show residual signs of Left Ventricular Hypertrophy. A reduction in voltage over left precordial leads was, however, noticed in 18 of 19 cases with pre-operative leads for comparison, and it may be that the standards accepted for voltage are too low at this age, particularly as previous investigation showed many normal children with "high voltage" in this age group.

SCHOOL AGE GROUP (b) 10 to 16yrs.

15 cases in this group had unipolar leads following operation. Eight with previous unipolar leads showed high voltage in the left precordial leads, and two in addition showed signs of Left Ventricular Hypertrophy.

Following ligation, four showed voltage within normal limits. Three, followed for one year and one recanalised, showed considerable reduction but remained above normal. Two with signs of Left Ventricular Hypertrophy showed reduction in these signs during a follow-up of six months and two years respectively.

Of the remaining seven without pre-operative comparison, five have normal Electrocardiograms. Two still show high voltage after eight and four years respectively.

One case has developed signs suggestive of Right Ventricular Hypertrophy.

ADULT GROUP

Ten cases survived operation above the age of 16 years. Of these, eight have had unipolar electrocardiograms, but unfortunately only three had unipolar leads taken prior to operation.

These three cases have been followed for six months to a year.

One (Case 42) with normal voltage before operation, remains so.

One (Case 59) with deep Q waves, tall R in V5 and deep S in V1, shows reduction in voltage but is still above normal.

One (Case 67) with similar high voltage shows no change.

The other five cases had no pre-operative unipolar leads for comparison. Three are normal, two show high voltage (one has calcified pleura, one has recanalised).

Thus of eight cases :-

four followed for one year or more are now within normal limits, but unfortunately in only one do we know the pre-operative state.

One recanalised, is still abnormal regarding voltage, and this latter is increasing with increase in signs of recanalisation.

One, with calcified pleura, is also abnormally high.

Two, followed for six months only, still show high

voltage, though one has diminished.

None of this group surviving operation showed ST.T changes before or after operation. Two cases in which there were previous ST.T changes both died at operation from cardiac arrest.

It is not possible to deduce anything from the above, because of our lack of knowledge of the pre-operative state in this group, particularly as on the whole the physical signs and radiological features would suggest that the cases, on the average, did not have large shunts.

Another interesting observation emerged in this study. In the school-age groups, 28 cases had electrocardiograms made within one month of operation - four had had previous evidence of Left Ventricular Hypertrophy, but the other 24, apart from high voltage in precordial leads, were normal.

The four cases with Left Ventricular Hypertrophy showed increase in the signs, one very markedly, while of the remaining 24,15 showed no change. Nine showed signs suggestive of Left Ventricular Hypertrophy for the first time, mostly in the precordial leads, but in some, changes were seen in Limb Leads and Standard Leads in addition.

These changes lasted from one to six months after ligation and have only persisted longer in two cases in the older group, both of which had shown signs of Left Ventricular Hypertrophy prior to operation. In both of these the signs are less.

One, unfortunately, has recanalised while the other has only been followed for six months and has shown progressive improvement in this time.

This appearance of Left Ventricular Hypertrophy immediately after ligation is not related to voltage prior to operation, and therefore some other explanation must be sought. Comparison with Cardiac Area does, however, show that in nearly all a very marked reduction in cardiac area had occurred following operation; and it is suggested that this may be due to reduction in dilatation of the Left Ventricle with resultant relative hypertrophy of the ventricular wall. If this is so, one must presume that these cases were bordering on Left Ventricular Hypertrophy prior to operation, and it is of interest that they did not consistently show high voltage. This would appear to be additional evidence that high voltage in the school child is not indicative of Ventricular Hypertrophy.

SUMMARY.

There are 30 cases in which unipolar lead Electrocardiograms are available both before and after ligation. 25 of these showed high voltage before operation, and 23 of these showed reduction in voltage after, but only nine became strictly normal. This pattern of high voltage may persist. In two adults, followed four and eight years respectively, it is still present in the absence of any other abnormal sign either clinically or radiologically.

Four cases with signs of Left Ventricular Hypertrophy before operation showed initial increase in signs immediately after, followed by progressive diminution in signs.

Nine out of 24 cases who had shown no abnormality prior to operation and who had Electrocardiograms carried out within one month after ligation, showed signs of Left Ventricular Hypertrophy in precordial leads lasting one to six months and then returned to normal. This has been correlated with a marked decrease in cardiac size immediately after operation. This would appear to be a similar pattern to that seen in the four cases with Left Ventricular Hypertrophy prior to ligation, all of whom showed increased signs of hypertrophy immediately after operation. It is suggested that these cases may have previously had minimal Left Ventricular Hypertrophy, made evident by the sudden decrease in the size of the ventricle.

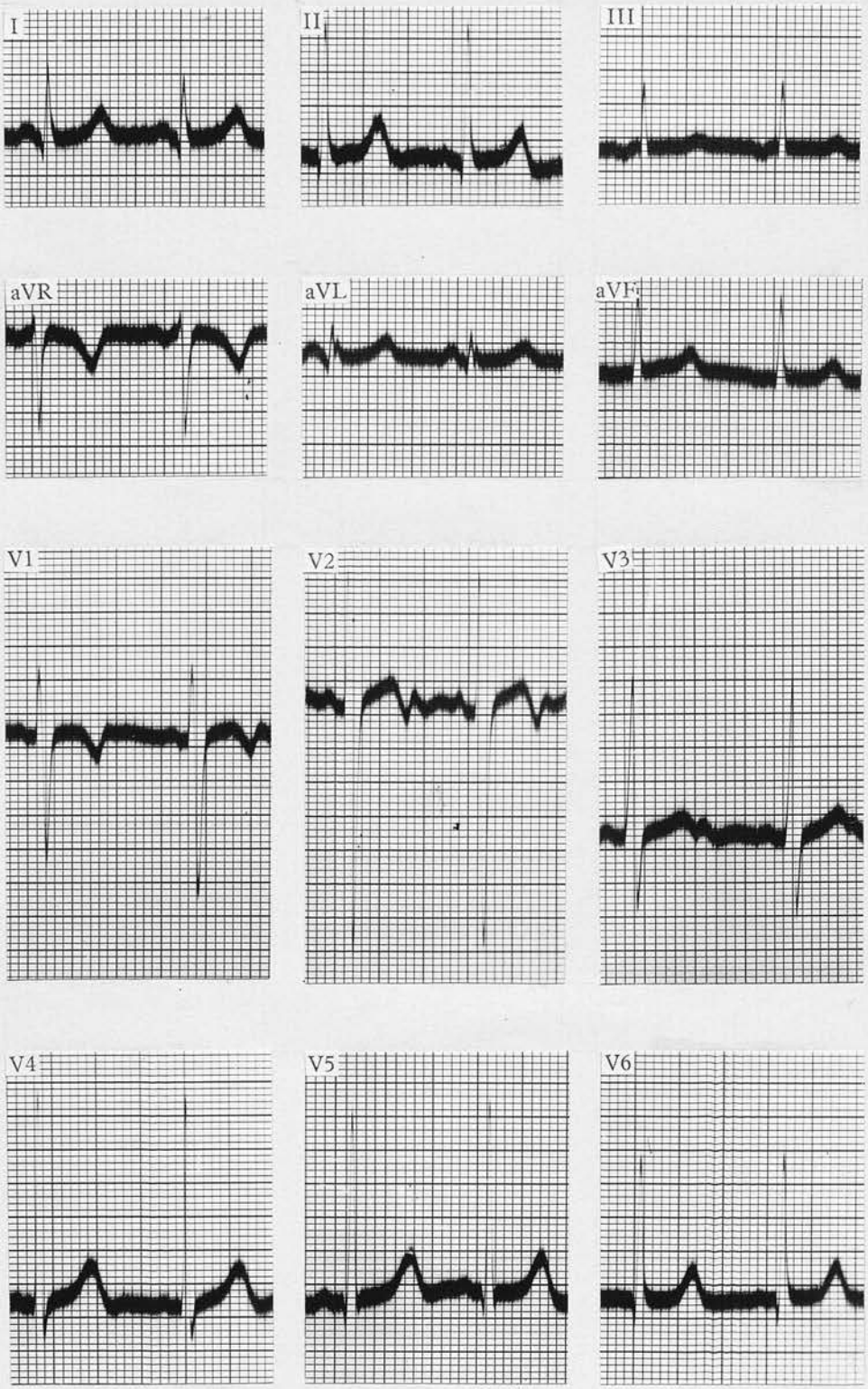


FIG. 39A Electrocardiogram of Case 60. High Voltage with marked reduction in voltage after ligation of Patent Ductus Arteriosus (9yrs.)
Before ligation - Tall R in V5, V6. Deep S in V1. R in V5 + S in V1 = 40mm.

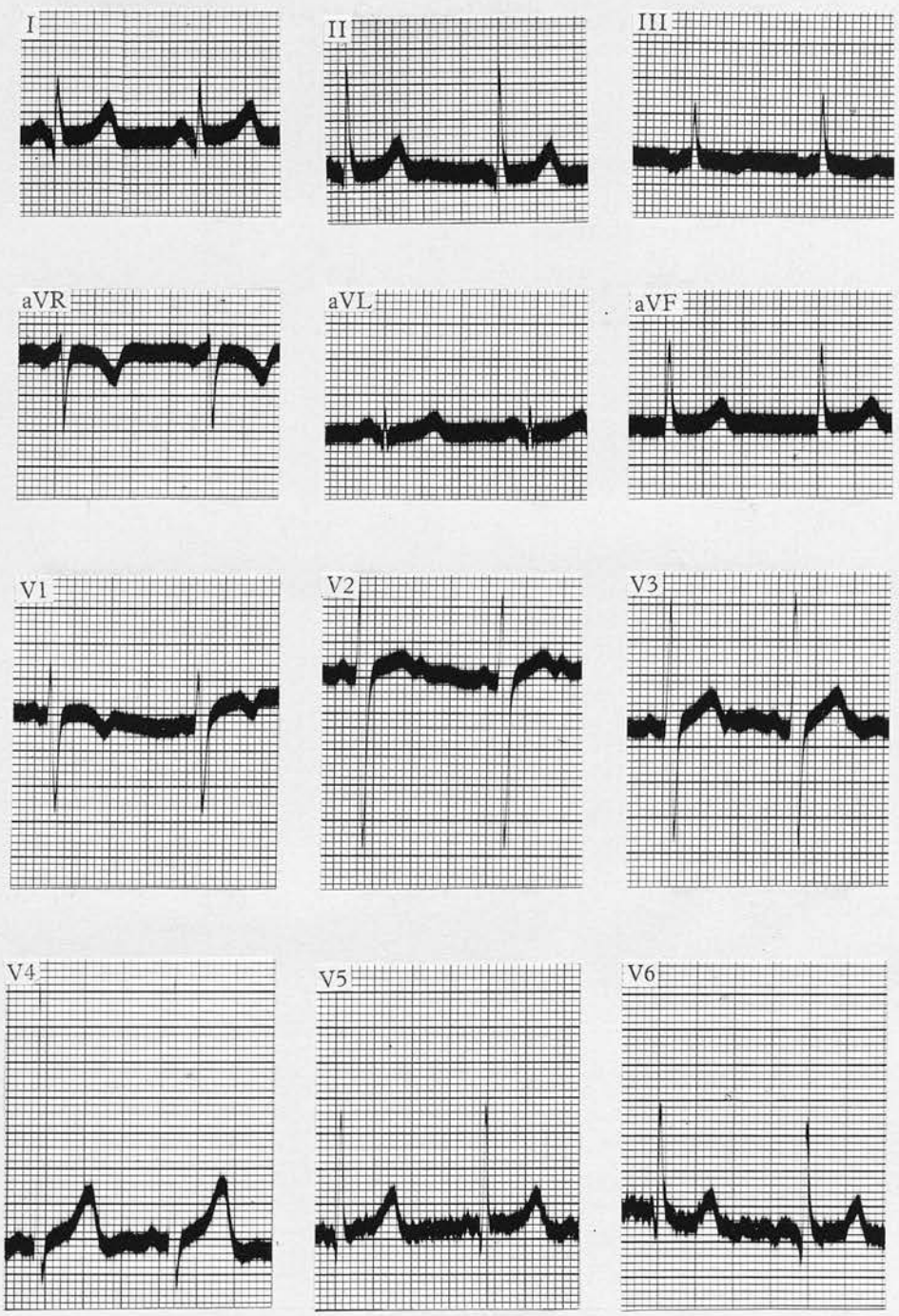


FIG. 39B Electrocardiogram of Case 60. High Voltage with marked reduction in voltage after ligation of Patent Ductus Arteriosus (9yrs.)
3 months after ligation - Normal Electrocardiogram
R in V5 + S in V1 = 28mm.

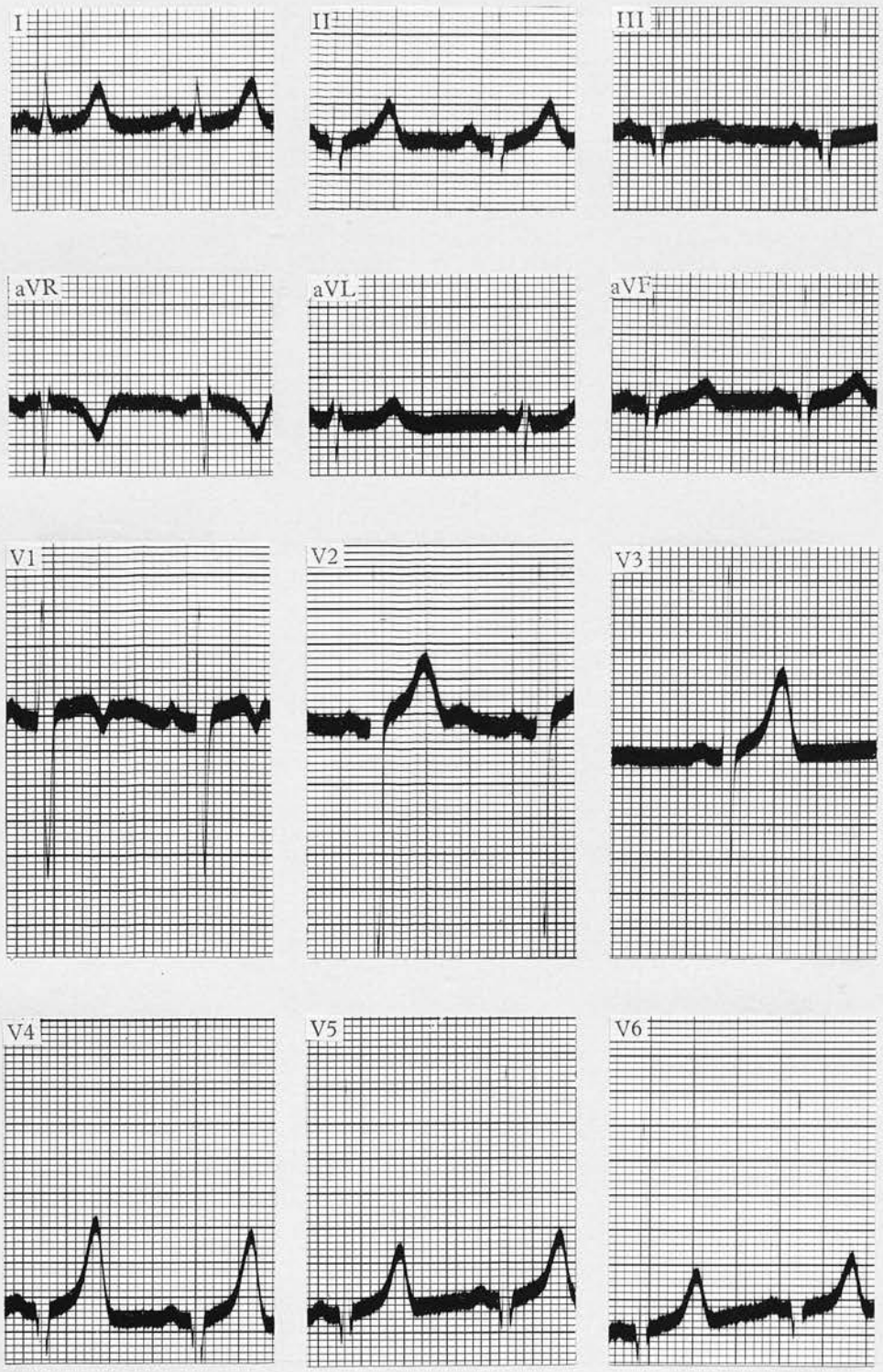


FIG. 40A Electrocardiogram of Case 63. High Voltage with reduction in voltage and minimal ST depression in Left Precordial Leads following operation.

Before ligation - Tall R V5, V6. Deep S in V1
R in V5 + S in V1 = 50mm.

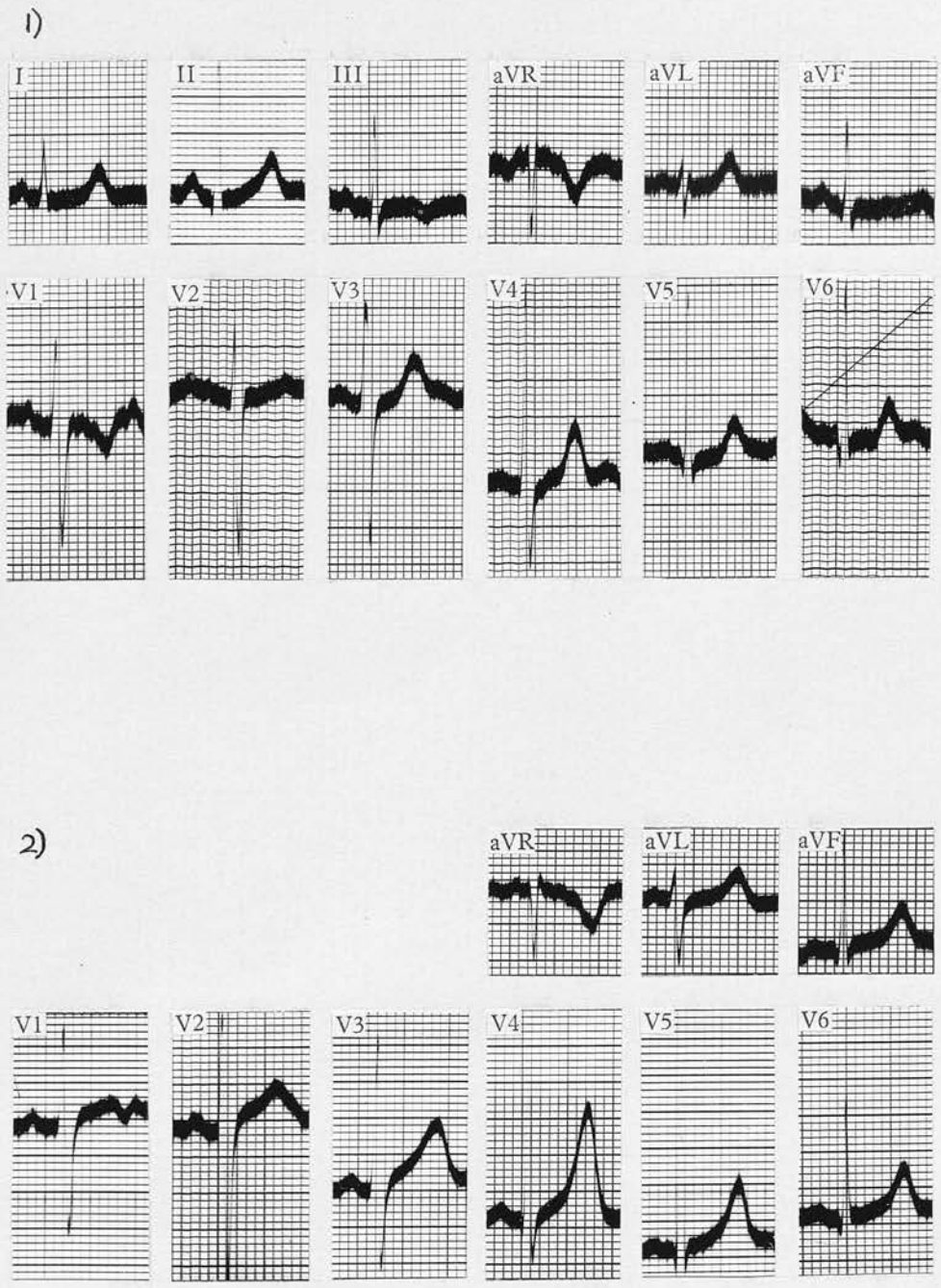


FIG. 40B Electrocardiogram of Case 63. High Voltage with reduction in voltage and minimal ST depression in Left Precordial Leads following operation.

1) 1 month after ligation - Reduction in voltage 1mm. ST depression V4-V6

2) 6 months after ligation Normal Electrocardiogram

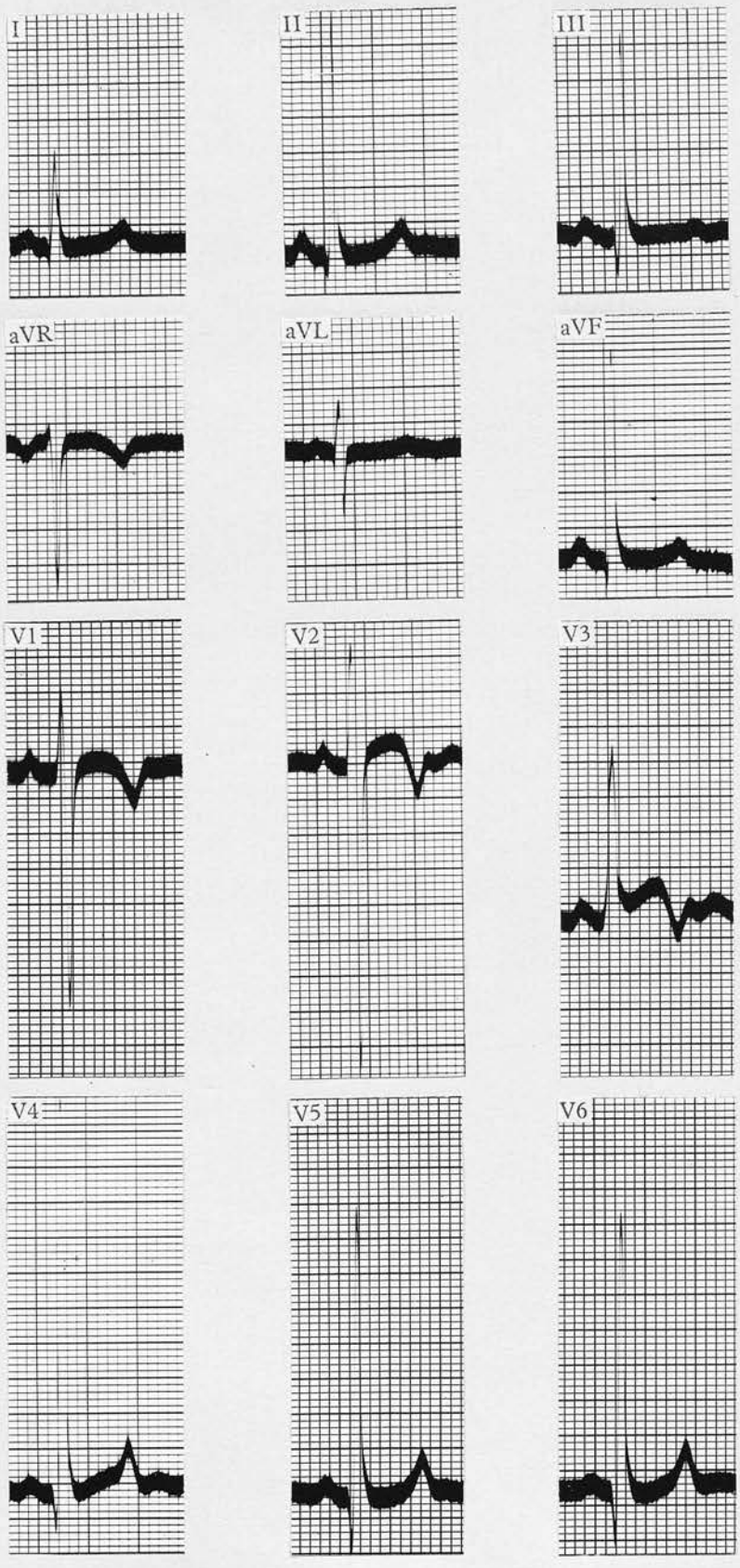


FIG. 41A Electrocardiogram of Case 64. High Voltage - with reduction in voltage and T inversion in precordial leads after ligation

Before ligation - Deep Q waves, very tall R V5,V6, and aVF - suggesting Left Ventricular Hypertrophy. No ST.T changes

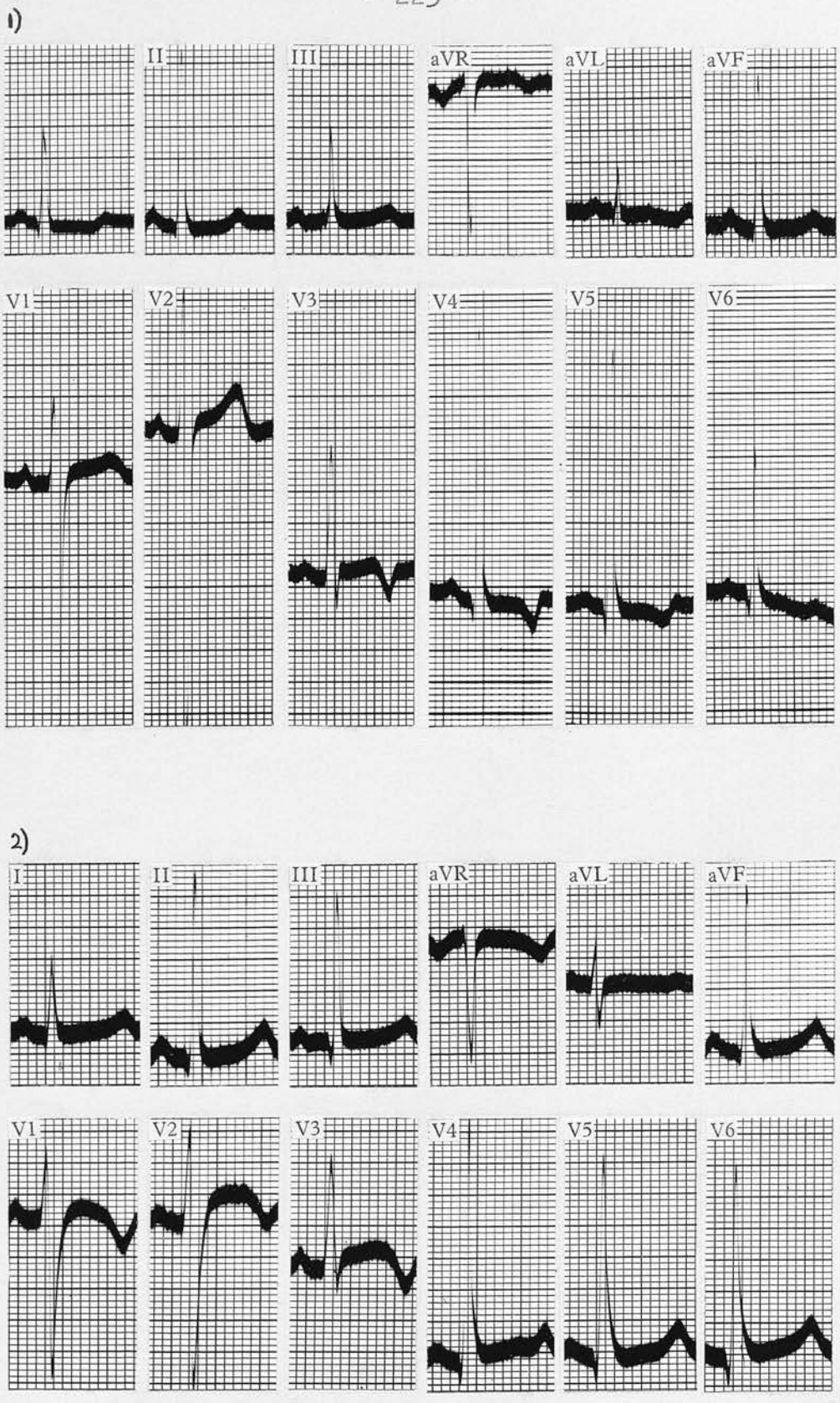


FIG. 41B Electrocardiogram of Case 64. High Voltage - with reduction in voltage and T inversion in precordial leads after ligation.

1) 1 month after ligation - diminution in Q waves, T inversion V4 - V6

2) 3 months after ligation Normal Electrocardiogram apart from slightly high voltage

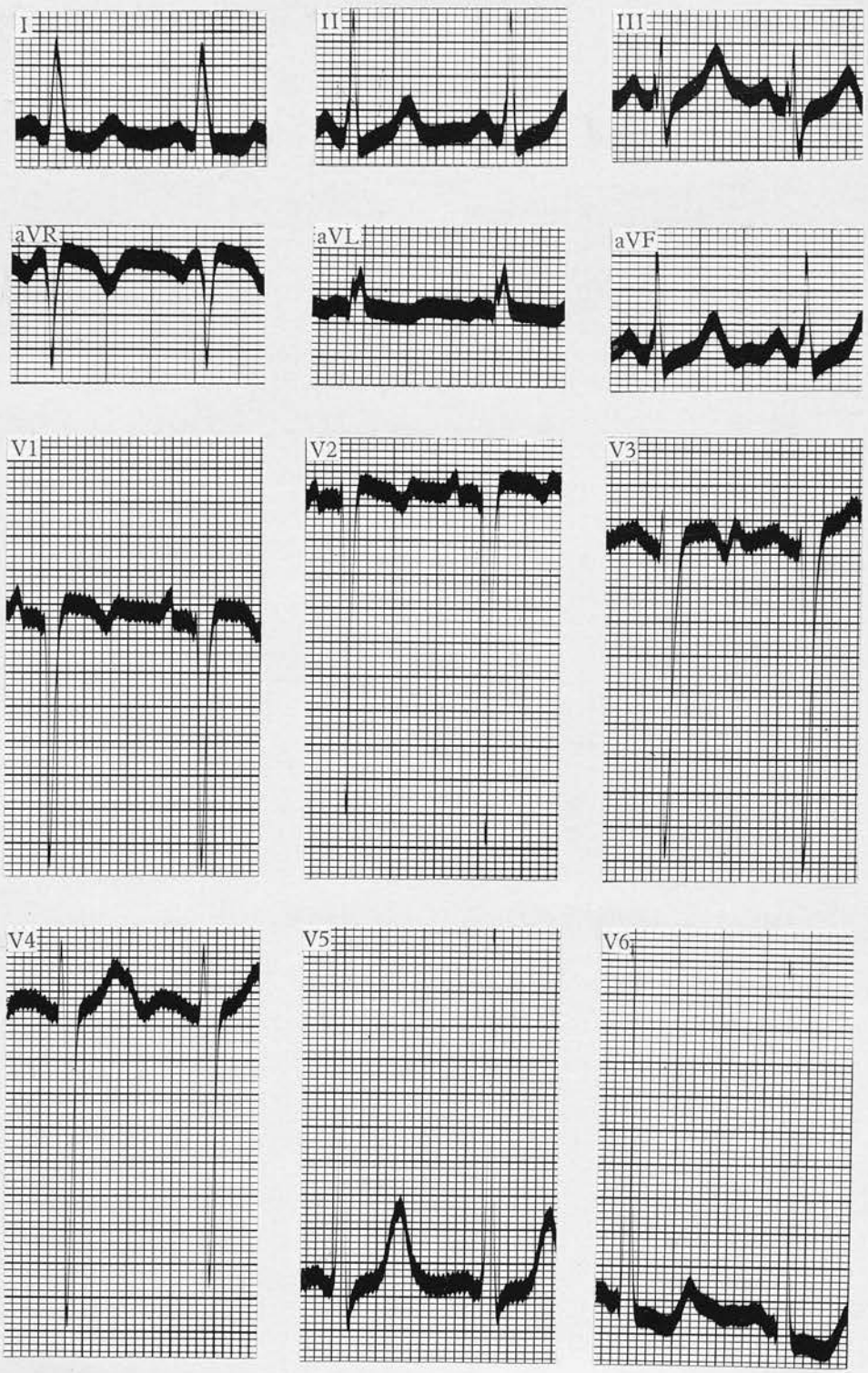


FIG. 42A Electrocardiogram of Case 68. Left Ventricular Hypertrophy with gross increase in signs after ligation of Patent Ductus Arteriosus.
Before operation - Signs of Left Ventricular Hypertrophy in I, II, aVF and V5, V6.
(ST depression, diphasic T waves)

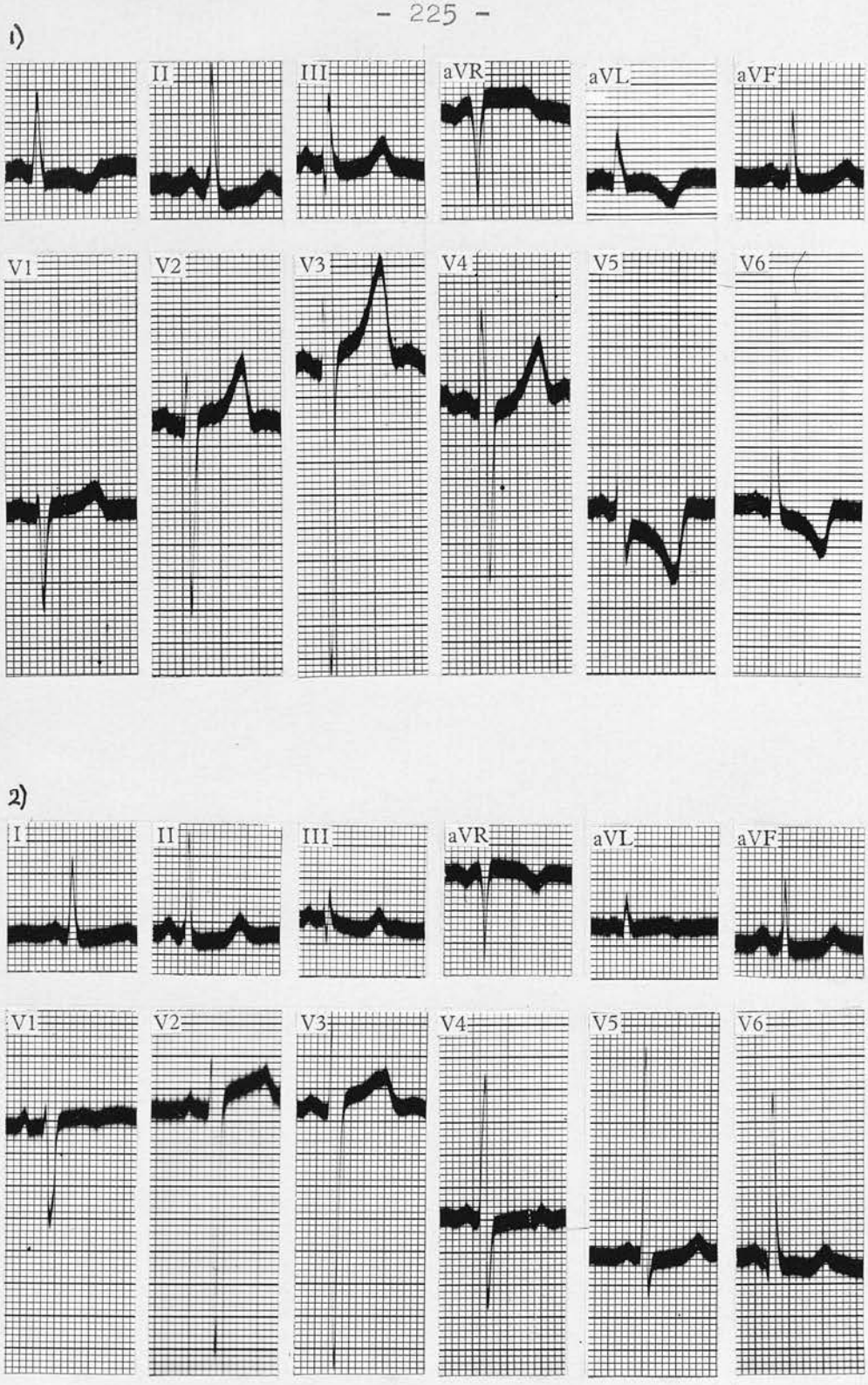


FIG. 42B Electrocardiogram of Case 68. Left Ventricular Hypertrophy with gross increase in signs after ligation of Patent Ductus Arteriosus.

1) 2 months after ligation - Gross signs of Left Ventricular Hypertrophy in I, II, aVL and precordial leads. ST depression and steep T inversion.
2) 4 months after ligation - Marked regression in signs. ST depression in V5,V6 now minimal.

THE INFECTED DUCTUS

INCIDENCE.

Abbott (1936) found Infective Endarteritis of the Pulmonary Artery and the Pulmonary end of the Ductus Arteriosus to be the cause of death in 30% of 92 fatal cases of Patent Ductus Arteriosus. Similarly, Keys and Shapiro (1943) found infection to be the cause of death in 41.7% of 60 fatal cases. It is thus a formidable complication.

In this series of 110 cases, 101 were first seen as uncomplicated cases of Patent Ductus Arteriosus and in none did infection supervene. Nine cases were referred primarily because of infection superimposed on Patent Ductus Arteriosus.

Age Incidence.

The youngest cases were 6 and 7 years respectively. The other seven were all adult, aged 16, 19, 19, 26, 27, 29 and 32 years respectively.

Sex Incidence.

Six of the cases were female and three male.

AETIOLOGY.

Organism (from Blood Culture).

Streptococcus Viridans	6 cases
Staphylococcus Aureus	1 case
Not known	2 cases

Source of Infection.

Tooth extraction	1 case
Root abscess	1 case
Measles	1 case
Not known	6 cases

Duration of Infection prior to Diagnosis.

Under one month	2 -	both recovered
One to three months	3 -	one recovered, two died
Three to six months	2 -	~~both~~ one died
Over six months	2 -	one recovered, one died

CLINICAL FEATURES.

Symptoms.

The chief symptoms were loss of weight, pallor, tiredness, fever, cough and pain in the chest, not all of which were present in any one case. In five the original diagnosis was Pneumonia, in one Pericarditis, in one Phthisis, in one Influenza and in the ninth Pyrexia of unknown origin.

Physical Signs.

The auscultatory findings and Blood Pressure studies in the nine cases are given in Table XXXII, which follows :-

TABLE XXXII

Physical Signs in Nine Cases of Infected Patent Ductus Arteriosus

Case No.	Age	Syst.P.	Diast.P.	Pulse P.	Thrill	Gibson Murmur	
14	6	100	44	56	+	III	Mary Beath
39	7	105	20	85	+	III	Jean McRae
20	16	130	48	82	+	II	Ingram
52	19	120	60	60	-	I-II	✓
1	19	110	50	60	-	III	✓
25	26	120	65	55	+	III	Eadie
21	27	100	50	50	+	II	Fraser
12	29	148	42	106	+	II	✓
30	32	146	45	101	+	III	✓

The most noteworthy feature is the high Pulse Pressure present in most cases (average 73mm. Hg.). With one exception, all had well-marked signs of Patent Ductus on auscultation.

Investigations showed a positive Blood Culture in seven of the nine cases. Haemoglobin was low and varied from 52% to 78% (six fell below 70%). W.B.C. was in the region of 10,000 per c.m.m. in all. B.S.R. ranged from 24 to 70mm. fall in an hour, with a sharp rise to 100mm. in two cases immediately after Pulmonary Infarction.

Radiological Features.

These were studied as in the non-infected cases.

Cardiac Size. All but one showed generalised cardiac enlargement on the whole greater than in the uncomplicated case. The average Cardiac Area was +35% above normal. Two cases with serial Radiographs taken during control of the infection with Penicillin were of interest, as they illustrated the reversibility of the cardiac enlargement which occurs during the infective process. In Case 39, cardiac area was reduced from +66% to +44% and in Case 52 from +15% to -5% during Penicillin therapy.

Great Vessels. There was marked enlargement of the Pulmonary Artery in all cases but one in which the enlargement was only slight. Case 39 developed a Pulmonary Aneurysm which continued to increase in size after the infection was controlled.

Hilar Vessels and Lung Fields. Increased

vascularity was present in all, but hilar dance only in two. In six, there was evidence of infarcts. In five, the infarcts were bilateral; in the sixth, on the left side only.

Left Atrial enlargement was not seen in any case.

Screen examination showed typical pulsation in all.

Electrocardiography.

Unipolar electrocardiograms were only made in two cases.

Case 39 had deep Q waves and tall R waves over left precordium suggesting Left Ventricular Hypertrophy. Associated with Pulmonary infarction, there were signs in the electrocardiogram - inverted T waves across the precordium.

Case 52 showed high voltage, tall R with T inversion in aVL, suggesting slight Left Ventricular Hypertrophy, which was confirmed at autopsy.

TREATMENT.

Three cases were treated with Penicillin 0.5 million units daily, and in all three the infection was controlled. Two cases were moribund at the start of treatment and following Penicillin therapy were fit enough for ligation to be undertaken successfully. The third case was only given Penicillin for eight days as there was some doubt as to the diagnosis. He died at operation later and was found at autopsy to have had Endarteritis which was healing.

Six cases had no Penicillin.

All nine cases were submitted to operation, three after control by Penicillin and six in the acute stage of the infection. Two of the former and three of the latter survived. The five survivors were all female. Of the four who died, three were male and one female. Two, before the advent of Penicillin, were moribund and died in spite of successful ligation. Two died at operation.

Cases controlled by Penicillin.

Case 39 Organism - haemolytic Staphylococcus Aureus.
Pulmonary infarcts. No systemic emboli.
Two months' illness.
600,000 units Penicillin daily for 28 days.
No positive culture after two days' therapy.
Subsequently developed Pulmonary Aneurysm - cured by ligation of Patent Ductus Arteriosus.

Case 52 Organism - not known.
Pulmonary infarcts. No systemic emboli.
Three months' illness.
500,000 units Penicillin daily for eight days.
No positive culture.
Died at operation of cardiac arrest (three months after onset of illness.
Autopsy: Showed the endothelium of the Pulmonary Artery above the Pulmonary Valve covered by an extensive plaque-like vegetation. The microscopic appearance was that of arrested Pulmonary Arteritis with healing (Fig. 44). The intima was irregular in depth

and showed considerable thickening.

In the deeper layers were numerous capillaries and collections of mononuclear cells, mainly histiocytes, some containing haemosiderin and some fibroblasts. Covering this was a delicate connective tissue containing plump and active fibroblasts obviously engaged in repair.

The lung showed multiple areas of infarction. The appearance of the arteries was unusual. Some showed thrombosis and subsequent recanalisation. Others showed complete disorganisation with disruption of Elastic Tissue and Giant Cell Reaction followed by fibrosis of media and intima (Fig. 44) - a type of process which suggested that the arteries themselves had suffered bacterial infection.

Case 21 Organism - Streptococcus Viridans.

Pulmonary and Systemic Emboli. Eight months' illness.

500,000 units Penicillin daily for 31 days.

No positive culture after start of therapy.

No further emboli after 15 days.

Fit for ligation of Patent Ductus on 28th day.

Subsequently recanalised.

<u>Cases treated by ligation alone</u>.

Case 14 Organism - Streptococcus Viridans.

Pulmonary infarcts. No systemic emboli.

Six months' illness.

Blood Culture, scanty growth two days after ligation.

Cured - No antibiotic therapy.

Case 20 Organism - Streptococcus Viridans.

No Pulmonary or systemic emboli. Nine days' illness.

Blood Culture, no growth 16 minutes after ligation.

Cured - No antibiotic therapy.

Case 25 Organism - Streptococcus Viridans.

No Pulmonary or systemic emboli. Three weeks' illness.

Blood Culture, no growth after ligation.

Cured - No antibiotic therapy.

Case 1 Organism - Streptococcus Viridans.

Pulmonary infarcts. No systemic emboli. Three months' illness.

Died two days after ligation, of massive collapse.

Case 12 Organism - not known (Staphylococcus Aureus in sputum).

Multiple Pulmonary infarcts. No systemic emboli. Six months' illness.

Died two days after ligation, of massive collapse.

Case 30 Organism - Streptococcus Viridans.

No Pulmonary or systemic infarcts.

Died at operation from haemorrhage.

FOLLOW-UP.

Clinical Features.

Five cases survived operation and all were cured.

Two (Cases 20 and 25) had no post-operative complication other than effusion. Heart sounds remained perfect, and they considered themselves more fit than before operation.

Case 14 had a small embolus in right lung on third day after operation. Thereafter had uneventful course. Improvement in nutrition immediately after operation was very striking (Fig. 45). Heart sounds have remained perfect. Child very fit.

Case 39 has shown steady though gradual improvement since operation. Remains thin, but has much more vigour (Fig. 75). Heart sounds are normal.

Case 21 made a remarkable recovery after ligation of Patent Ductus. Diastolic murmur persisted after operation, but six months later continuous murmur had returned. No recurrence of infection. General health much improved since ligation, but signs of recanalisation are increasing.

Radiological Features.

All have shown progressive decrease in size of heart since operation. Two years after ligation all were within normal limits with the exception of Case 21, in which the Ductus had recanalised.

Case 39 showed marked reduction in size of Pulmonary Aneurysm immediately after operation, and thereafter a gradual return to normality (Figs. 72,73).

Electrocardiography.

Case 39 showed increased signs of Left Ventricular Hypertrophy up to six months after ligation (associated with marked decrease in cardiac size). Thereafter, high voltage remained. Two years after operation, Electrocardiogram was normal.

In the other four cases the Unipolar Electrocardiogram was normal following operation.

SUMMARY.

Nine cases of Infected Ductus, none having developed under observation.

Age Incidence - 6yrs. to 32yrs.

Sex Incidence - six female, three male.

Origin of infection - Teeth 2 cases (Strept.Viridans)
Measles 1 case (Staph. Aureus)
Unknown 6 cases (Strept.Viridans)

Clinical Features.

In five of nine cases, earliest diagnosis was Recurrent Pneumonia.

Physical signs were classical and well-marked - high Pulse Pressure, Gibson Murmur II - III.

Positive Blood Culture obtained in seven of nine cases.

X-ray showed progressive increase in cardiac size during infection, which proved to be reversible under Penicillin therapy. There was also progressive increase in size of Pulmonary Artery, in one case reaching aneurysmal proportions.

Electrocardiogram reflected presence of Pulmonary Infarction, but was otherwise non-specific.

Treatment.

Three cases treated by Penicillin were all controlled (Fig. 44). Two, too ill for ligation, were later fit enough for successful operation.

Six cases, before advent of Penicillin, treated by ligation alone. Three cured without antibiotic. Two died in spite of successful ligation (extremely ill after three to six months' illness).
One died at operation.

Follow-up.

All five surviving operation were cured of Endarteritis.

Subsequent progress was similar to non-infected cases. Two years after operation, heart sounds normal, heart size normal, Electrocardiogram normal limits, with exception of one case which recanalised.

No subsequent reinfection.

Figures 43, 44, 45 illustrate

1. Appearance of heart and great vessels in untreated case of Infective Endarteritis of Pulmonary Artery associated with Patent Ductus Arteriosus.
2. Microscopic appearance of Endarteritis of Pulmonary Artery in healing stage, three months after Penicillin therapy.
3. Marked immediate improvement in nutrition following ligation of Patent Ductus Arteriosus.

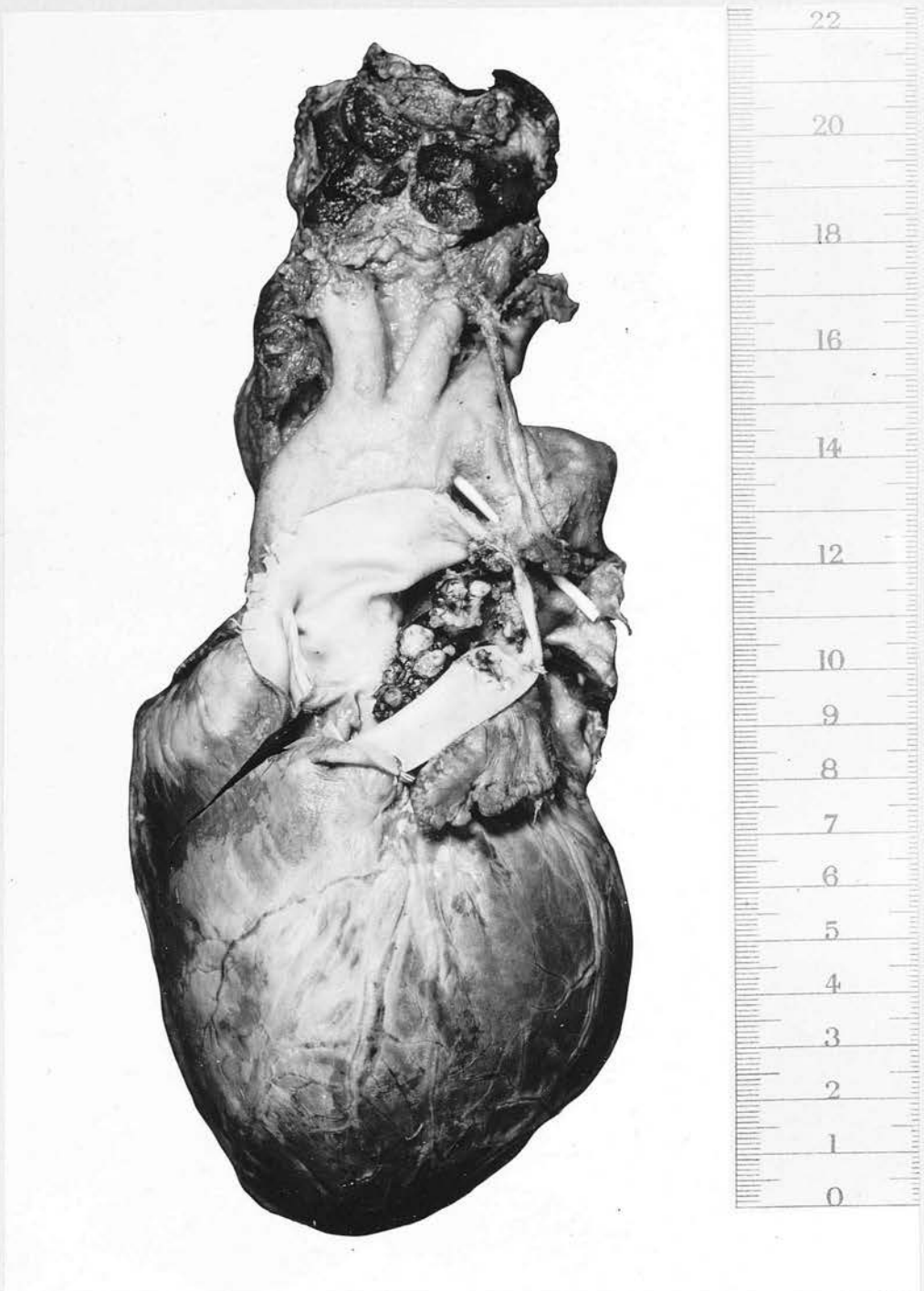
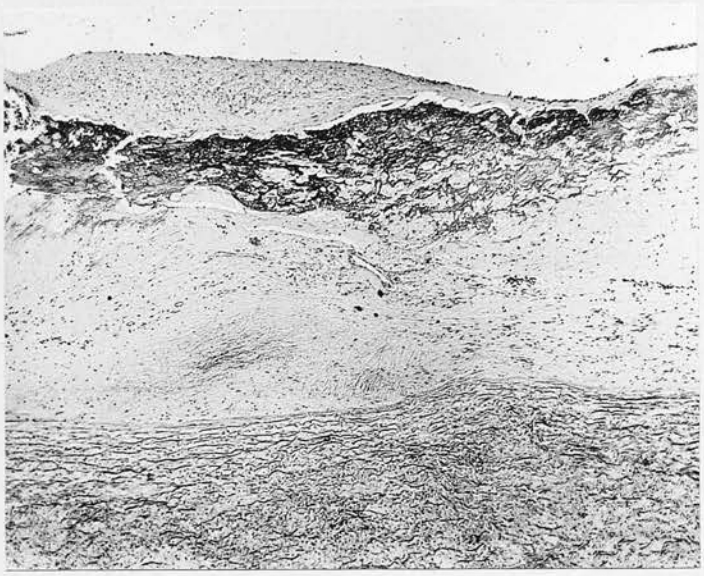


FIG. 43 Photograph of Heart of Case 12.
Infective Endarteritis of Pulmonary Artery
Marker inserted behind Ductus
Mass of vegetations in Pulmonary Artery extending almost to Pulmonary Valve
Tiny vegetation on one cusp of Pulmonary Valve

1)



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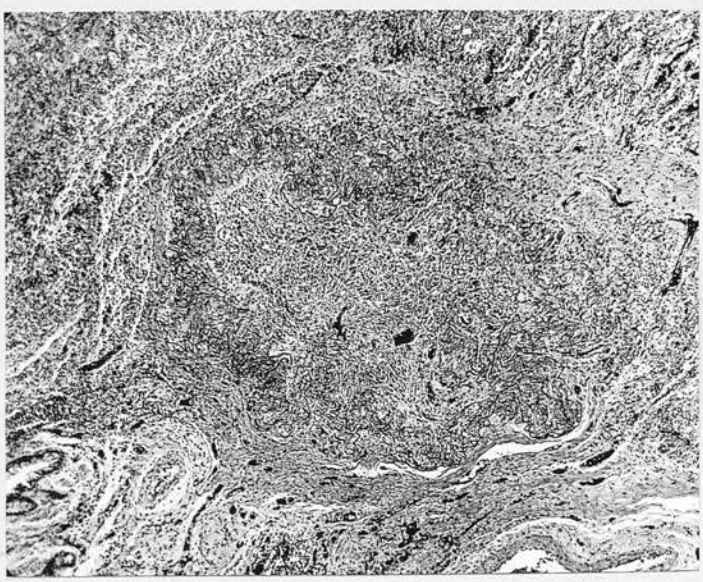


FIG. 44 1. Photomicrograph of Pulmonary Artery(x 45) of Case 52.
Arrested Pulmonary Arteritis with healing.
Covering layer of delicate connective tissue enclosing irregular acidophil strands of previous vegetation.
2. Photomicrograph of Lung (x 45)
Artery with disorganisation of elastic tissue and giant cell reaction suggesting bacterial infection (Arteritis).

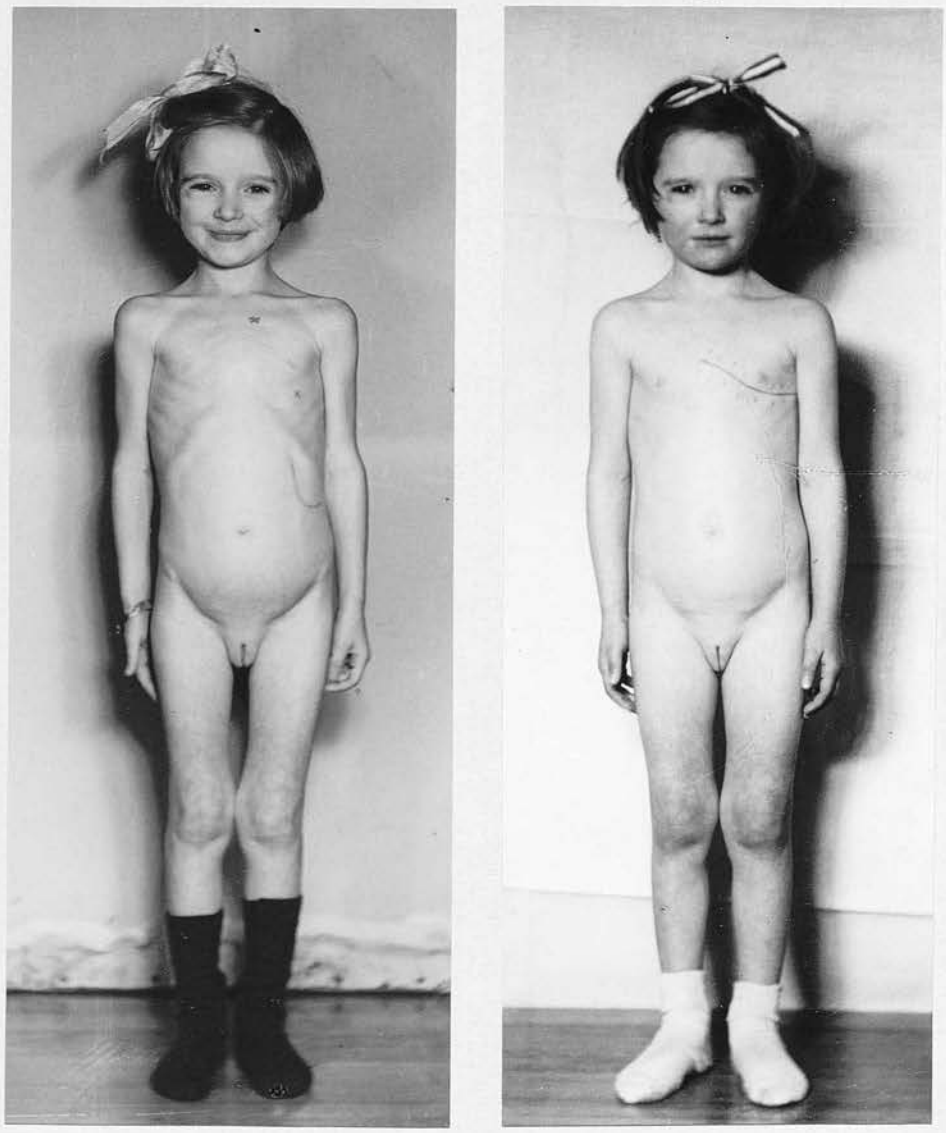


FIG. 45 Photographs of Case 14.
Patent Ductus with Infective Endarteritis of Pulmonary Artery.

1. Before ligation -
   Splenic enlargement. Nutrition poor.
2. 6 weeks after ligation -
   Scar of anterior approach.
   Marked improvement in nutrition.

CASES OF SPECIAL INTEREST, WITH ILLUSTRATIONS

1. Case 70 -

Large Patent Ductus in early adult life (25yrs.)
Radiological and Electrocardiographic evidence of Left Ventricular Hypertrophy.
Autopsy - Gross Left Ventricular Hypertrophy without generalised enlargement.

3 cases with difficulty regarding diagnosis.

2. Case 83 -

Patent Ductus associated with Mitral Disease.
Disappearance of Gibson Murmur in congestive failure.
Calcification in Arch of Aorta in X-ray, confirmed at autopsy.

3. Case 75 -

Stomal Patent Ductus with Shunt Reversal.
Central cyanosis. No Gibson Murmur.
Calcification in Arch of Aorta in X-ray.
Right and Left Ventricular Hypertrophy.

4. Case 71 -

Oldest case of Patent Ductus in series (64yrs.)
Absent or variable Gibson Murmur with Auricular Fibrillation and congestive failure.
Left Ventricular Hypertrophy. Calcification in Arch of Aorta. Persistence of Mitral Diastolic Murmur in failure.

3 cases with Post-operative Complications.

5. Case 45 -

Stomal Patent Ductus.
Partial recanalisation after ligation.

6. Case 46 -

Large Patent Ductus.

Partial recanalisation after ligation.

Development of calcifying pulsatile shadow in region of Left Pulmonary Artery, one year after operation.

7. Case 58 -

Large Patent Ductus.

Development of Periductal Haematoma three months after successful ligation.

8. Case 39 -

Patent Ductus with Infective Pulmonary Arteritis due to Staphylococcus Aureus.

Infection controlled by Penicillin.

Development of Pulmonary Artery Aneurysm.

Resolution after ligation of Patent Ductus.

Case 70. A.C., female, 25yrs.

Patent Ductus Arteriosus in early adult life

Radiological and Electrocardiographic evidence of Left Ventricular Hypertrophy.

Autopsy - Gross Left Ventricular Hypertrophy without marked generalised cardiac enlargement.

History - Condition poor at birth (limp and blue) after labour lasting five days. Thereafter well up to 17 years when she had palpitation, breathlessness and dizziness for two months. Noticed deterioration in exercise tolerance from 23 years on.

Examination - Above standard for height and weight. Fit-looking young woman. Well-marked signs of Patent Ductus with Gibson Murmur (III) and thrill. Second sound at Pulmonary area accentuated and split. Mid-diastolic Murmur at Mitral area. Corrigan Pulse. B.P. 130/68 (Rt. arm) 122/65 (Left arm). After exercise, B.P.140/30.
X-ray - Transverse diameter within normal limits. Cardiac area +15%. Enlargement of Left Ventricle. Appearances typical of Patent Ductus with enlargement of Pulmonary Artery and hilar vessels. No hilar dance. No enlargement of Left Atrium.
E.C.G. Tall R waves V4 - V6 with slight ST depression in V5, V6, suggesting Left Ventricular Hypertrophy.

Operation - Ligation undertaken at patient's request - because of deterioration in previous two years and uncertainty regarding future.
Large, thin Ductus found. Perforated posteriorly. Bleeding controlled after clamping and dividing Ductus. Death occurred from sudden cardiac arrest during pressure to control bleeding from small Bronchial Artery.

Autopsy - Confirmed presence of gross Left Ventricular Hypertrophy.

Figures 46, 47, 48 illustrate the radiological, electrocardiographic and autopsy appearances.

1.

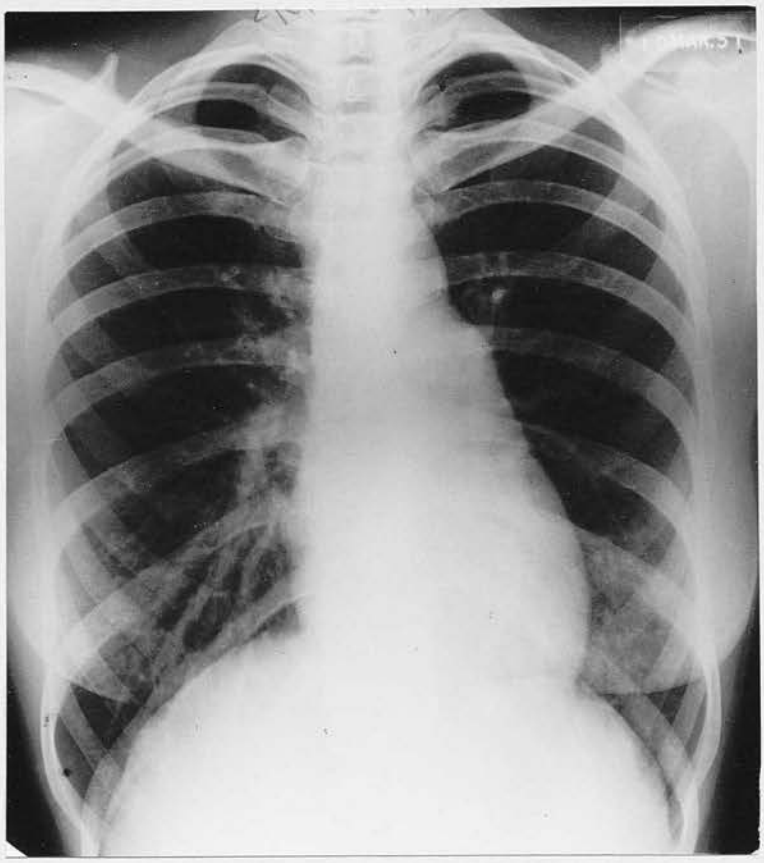
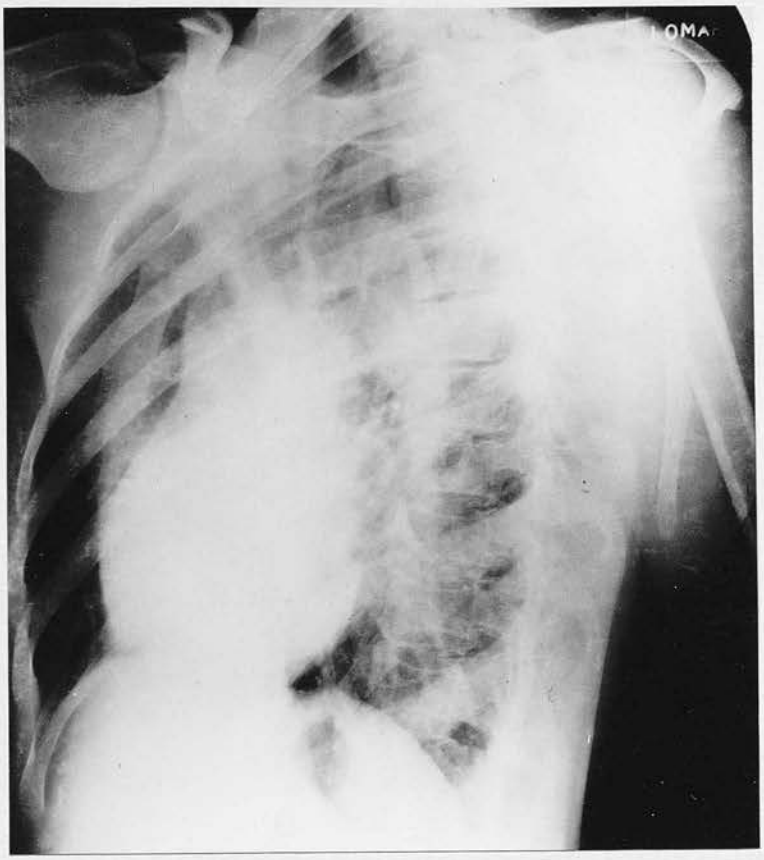


FIG. 46 Radiograph of Case 70. Patent Ductus aged 25 yrs.
1. P.A. 2. L.A.Obl. 3. R.A.Obl.
Slight generalised cardiac enlargement (C.A.+15%)
Left Ventricular enlargement
Doubtful enlargement of Left Atrium, not confirmed on screen.

2.



3.

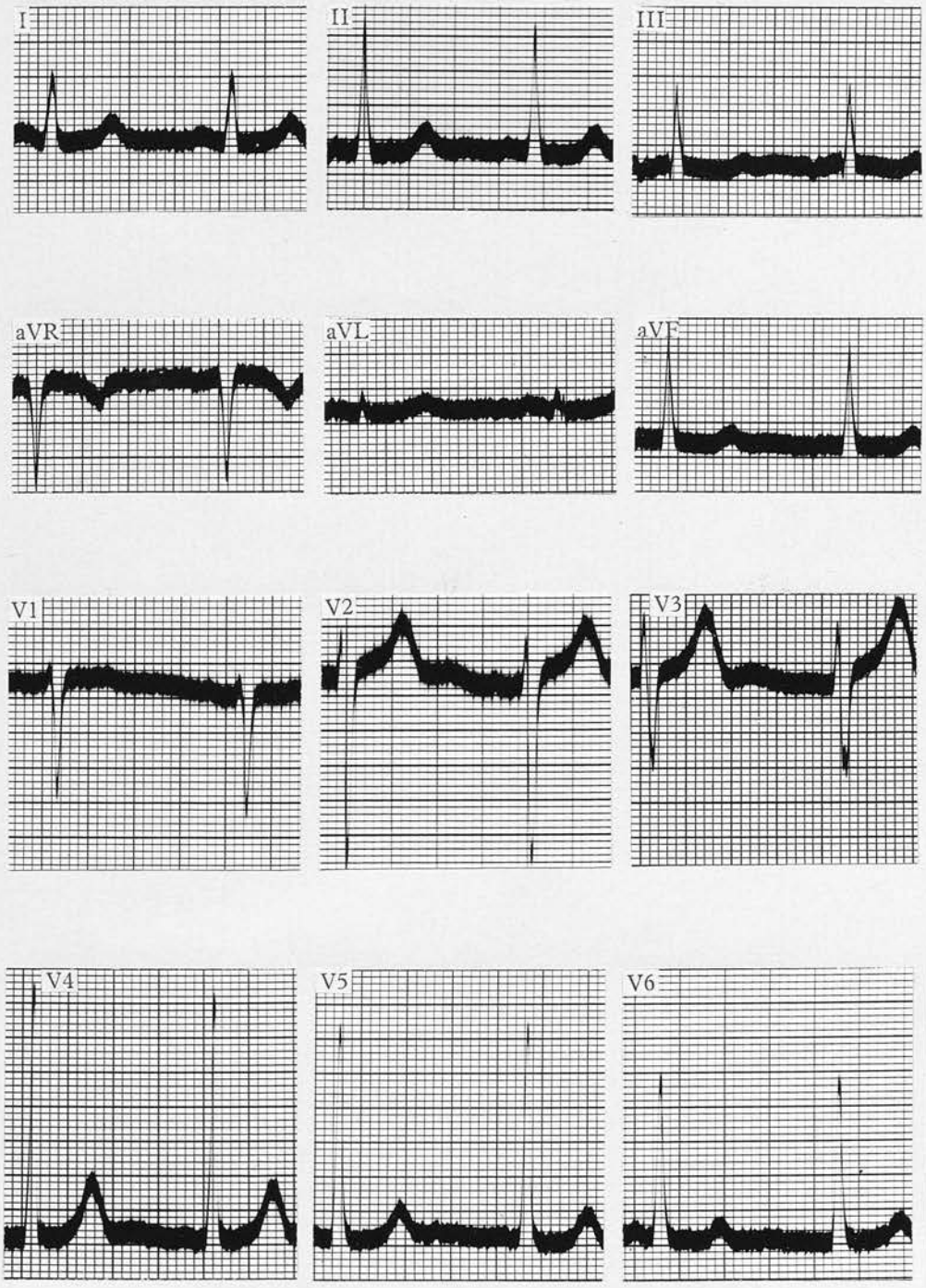


FIG. 47 Electrocardiograph of Case 70. Patent Ductus aged 25yrs.
Tall R waves V4,V5,V6, deep S in V1
Slight ST depression V5, V6
Suggesting Left Ventricular Hypertrophy

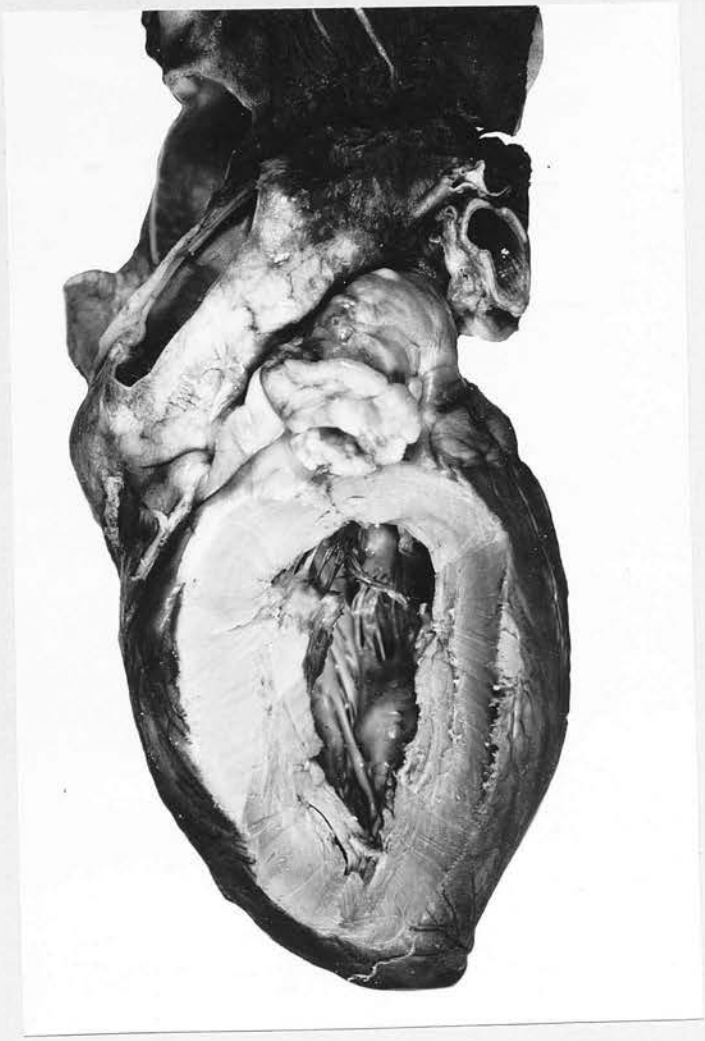


FIG. 48 Photograph of Heart of Case 70.
Patent Ductus Arteriosus
Extreme Left Ventricular Hypertrophy
without gross cardiac enlargement.

Case 83. D.M., female, 23yrs.

Patent Ductus associated with Mitral Disease

Difficulty in diagnosis due to disappearance of Gibson Murmur in congestive failure.

Calcification in Arch of Aorta in X-ray, confirmed at autopsy.

History - Rheumatic Heart Disease from 4 years of age. Tiredness since childhood. Attacks of tachycardia from 14 years.

Examination - Originally admitted in critical state with Fast Auricular Fibrillation and congestive failure. Corrigan Pulse noted. Signs of Mitral Stenosis but no Aortic Regurgitation. No Gibson Murmur. With relief of congestive failure soft Gibson Murmur (I) and thrill appeared. B.P.130/60, after mild exercise 190/30. Continued to have attacks of Nodal Tachycardia and Auricular Fibrillation. Finally, she developed congestive failure which failed to respond to therapy, and she died (1½ years after first admission). X-ray showed well-marked cardiac enlargement (C.T.R. 60.3). Mitral shape with marked enlargement of Left Atrium. Aortic knuckle small and poorly defined. Calcification in Arch of Aorta. Unusually brisk pulsation over Left Ventricle on screen and slight expansile pulsation of hilar vessels. No unipolar Electrocardiogram.

Autopsy - 1) Mitral Valve thickened and hardened, partly calcified. Three fingers admitted.
2) Ductus Arteriosus admitted large probe - Funnel-shaped, Aortic end wide, Pulmonary end narrow. Aortic end stippled with calcified granules of Atheroma. No Atheroma in Pulmonary Artery.

Figure 49 illustrates radiological appearance, with gross enlargement of Left Atrium and calcification in Arch of the Aorta.

1. P.A.

2. R.A.O.

FIG. 49 Radiograph of Case 83. Patent Ductus with Mitral Stenosis, aged 23yrs.
Gross cardiac enlargement
Calcification in Aorta
Marked enlargement of Left Atrium

Case 75. A.G., male, 47 yrs.

Stomal Patent Ductus with Shunt Reversal.

1) Aorta to Pulmonary Artery.

Left Ventricular Hypertrophy.

Large Pulmonary Artery and expansile hilar vessels.

2) Pulmonary Artery to Aorta.

Right Ventricular Hypertrophy.

Right Bundle Branch Block.

Absence of Gibson Murmur.

Difficulty in diagnosis in presence of Shunt Reversal.

Value of Left Ventricular Hypertrophy, calcification in Aorta and persistence of signs of Mitral Stenosis in spite of congestive failure in establishing diagnosis of Patent Ductus. Appearances otherwise like Lutembacher's Syndrome.

History - No disability till 45 years of age. Thereafter progressive exertional dyspnoea and cyanosis.

Examination - Severe congestive failure, oedema of ankles, sacrum and ascites with gross cardiac enlargement. Systolic Murmur audible all areas. Mid-diastolic murmur at Mitral Area and early diastolic at Pulmonary Area. Investigations proved cyanosis to be central in type (Arterial Oxygen Saturation 78%, Hb. 140%).
X-ray showed gross cardiac enlargement involving both Ventricles, though mainly Right.
Calcification in Arch of the Aorta. Expansile pulsation of hilar vessels.
E.C.G. - Auricular Fibrillation, Partial Right Bundle Branch Block. Tall R, ST depression, T inversion over left precordium. ? Left Ventricular Hypertrophy but under Digitalis therapy.

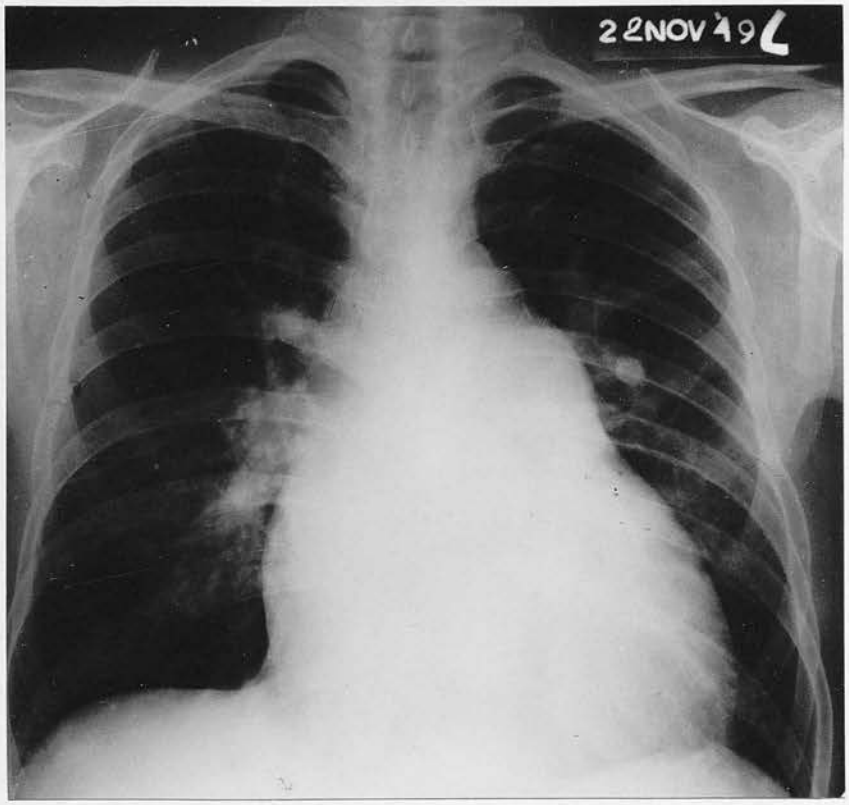
Progress - Congestive failure slow to clear but finally responded to Digitalis, Mersalyl and low salt diet. No change in cardiac signs with relief

of failure. Well-marked pulsation from internal to apex up to Pulmonary Area. Apical systolic and long rumbling mid-diastolic murmur. At base, soft systolic murmur followed by widely split but unaccentuated second sound and long blowing Diastolic Murmur. Congestive failure returned and he died suddenly one year after onset.

Autopsy - Stomal Ductus approximately 10mm. diameter. Hypertrophy and Dilatation of both Ventricles. No Septal Defects.

Figures 50, 51 show radiological features and appearance of heart at autopsy.

1)



2)

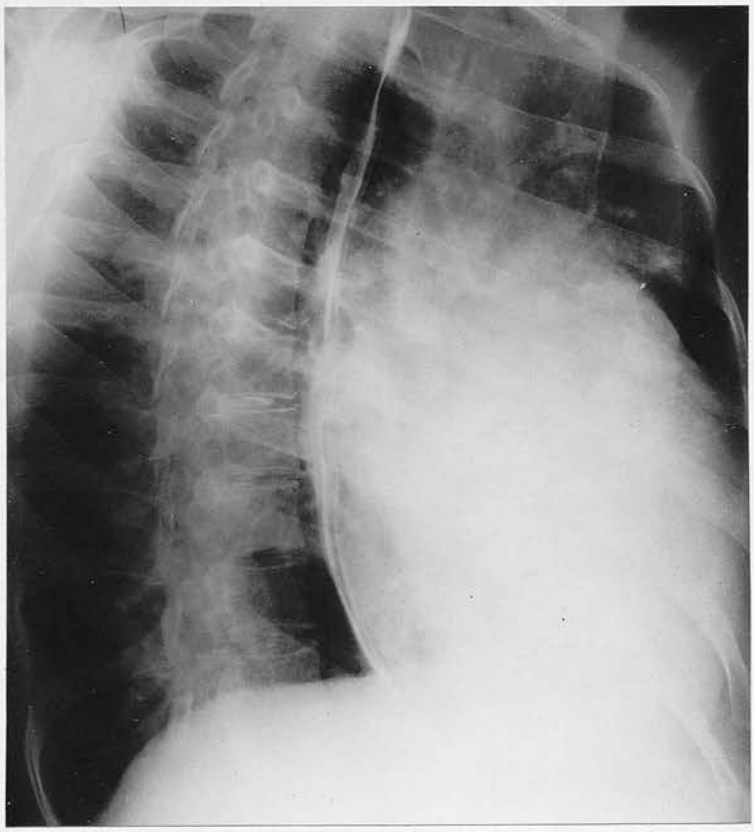


FIG. 50 Radiograph of Case 75. Stomal Ductus with Shunt Reversal.
1. P.A. 2. R.A.O.
Gross cardiac enlargement
Large Pulmonary Artery and congested lung fields.
Calcification in Arch of Aorta.

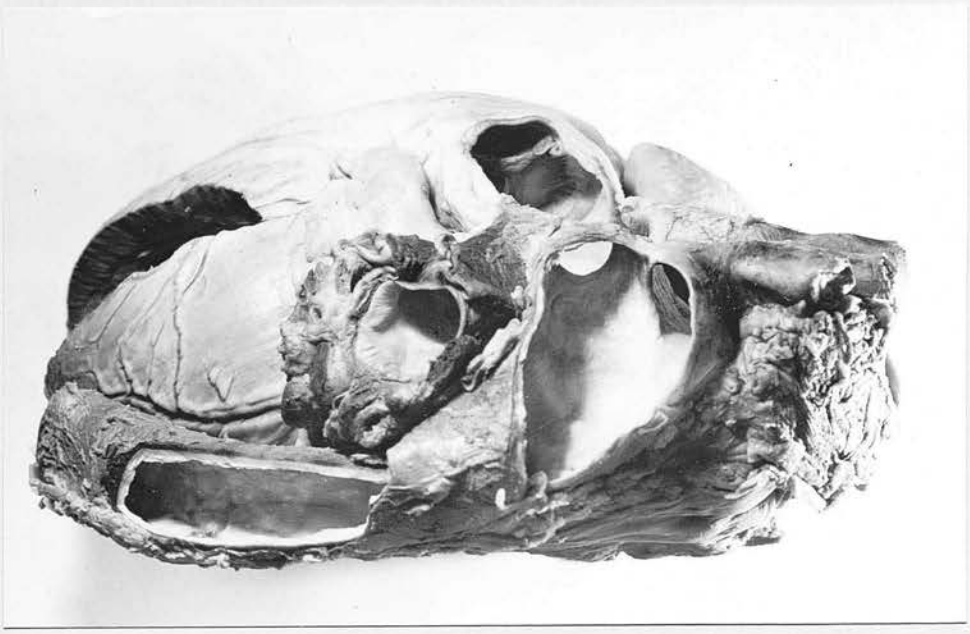


FIG. 51 Photograph of Heart of Case 75.
Stomal Ductus between Aorta and Pulmonary Artery.
Enlargement of Pulmonary Artery.

Case 71. W.H., male, 64yrs.

Oldest case of Patent Ductus in series.

Difficulty in diagnosis with Fibrillation and congestive failure due to absent or variable Gibson Murmur.

Value of Aortic Calcification, Left Ventricular Hypertrophy, enlargement of Pulmonary Artery and Mitral mid-diastolic Murmur in establishing diagnosis.

History - Known to have heart disease from 19 years of age. No symptoms until 59 years, when he developed breathlessness on exertion. Nocturnal cough and breathlessness from 63 years on.

Examination - Well-developed man. In mild congestive failure when first seen, with fast fibrillation, collapsing pulse. B.P.150/55. Marked mid-diastolic murmur in Mitral area. No Gibson Murmur. With digitalisation and disappearance of failure, low-pitched Gibson Murmur associated with slight thrill appeared, associated with accentuated and split second sound at Pulmonary area. Systolic and diastolic murmurs sometimes became discontinuous after exercise, but joined up with rest. Mitral mid-diastolic murmur remained. Exercise test, in failure, was negative but drop in diastolic pressure was easily elicited after digitalisation.
X-ray - Marked cardiac enlargement (Cardiac Area +100%) with gross enlargement of Left Ventricle, Pulmonary Artery, hilar and lung vessels. The Aorta was normal in size and showed calcification low in the Arch close to the shadow of the enlarged Pulmonary Artery. Screen examination showed no increased pulsation in heart and great vessels.
E.C.G. - Tall R waves V5 - V8 with ST depression and T inversion in standard, limb and precordial leads, indicative of Left Ventricular Hypertrophy. QRS in standard and unipolar limb leads increased to 0.12 sec.
Investigations (Arterial Oxygen, Venous Pressure, Circulation Times) showed slight cyanosis present to be peripheral in type (no Shunt Reversal). Failure was mainly Left Ventricular.

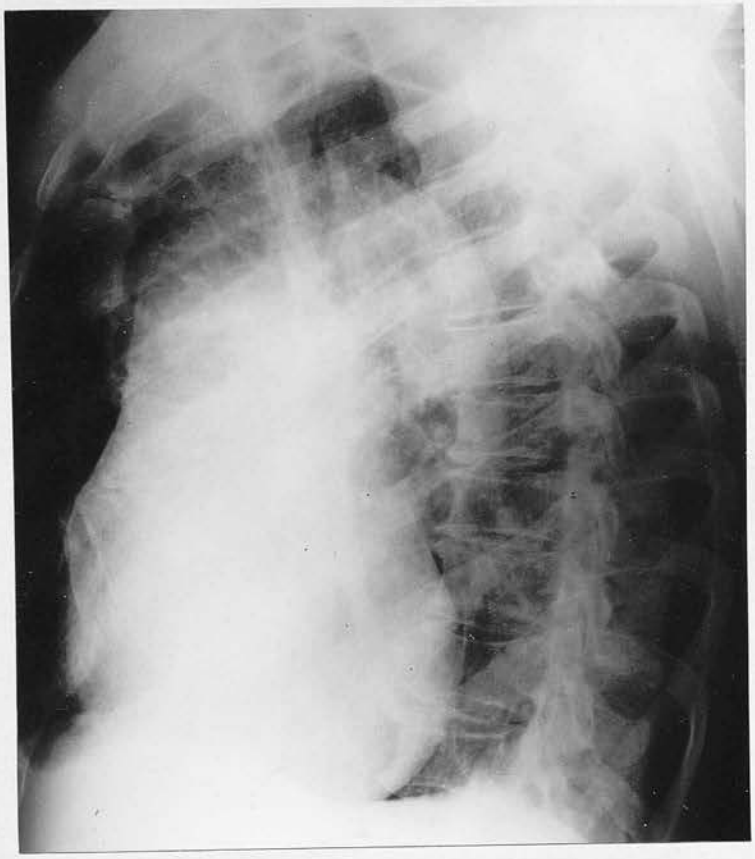
Progress - During three months' observation, digitalisation relieved nocturnal breathlessness, but improvement was not dramatic.

Figures 52, 53 illustrate radiological and electrocardiographic appearances.

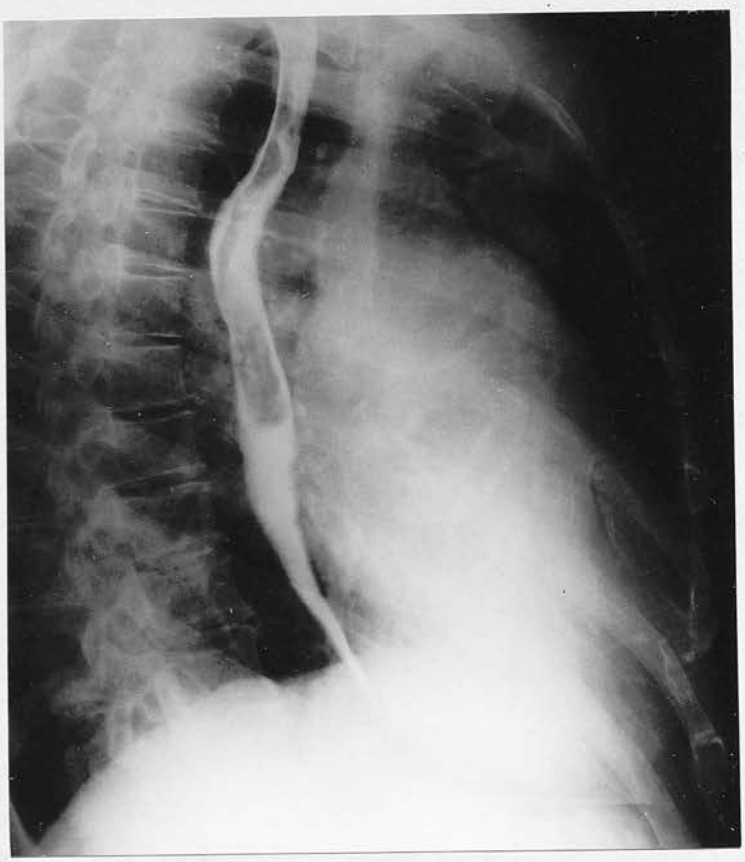
1)

FIG. 52 Radiograph of Case 71. Patent Ductus aged 64yrs. with calcification in Arch of Aorta.
1) P.A. 2) L.A.O. 3) R.A.O.
Gross cardiac enlargement (C.A. +100%)
Left Ventricular Hypertrophy
Marked enlargement of Pulmonary Artery
Congestion of LungFields
Calcification low in Aortic Arch
Enlargement of Left Atrium

2)



3)



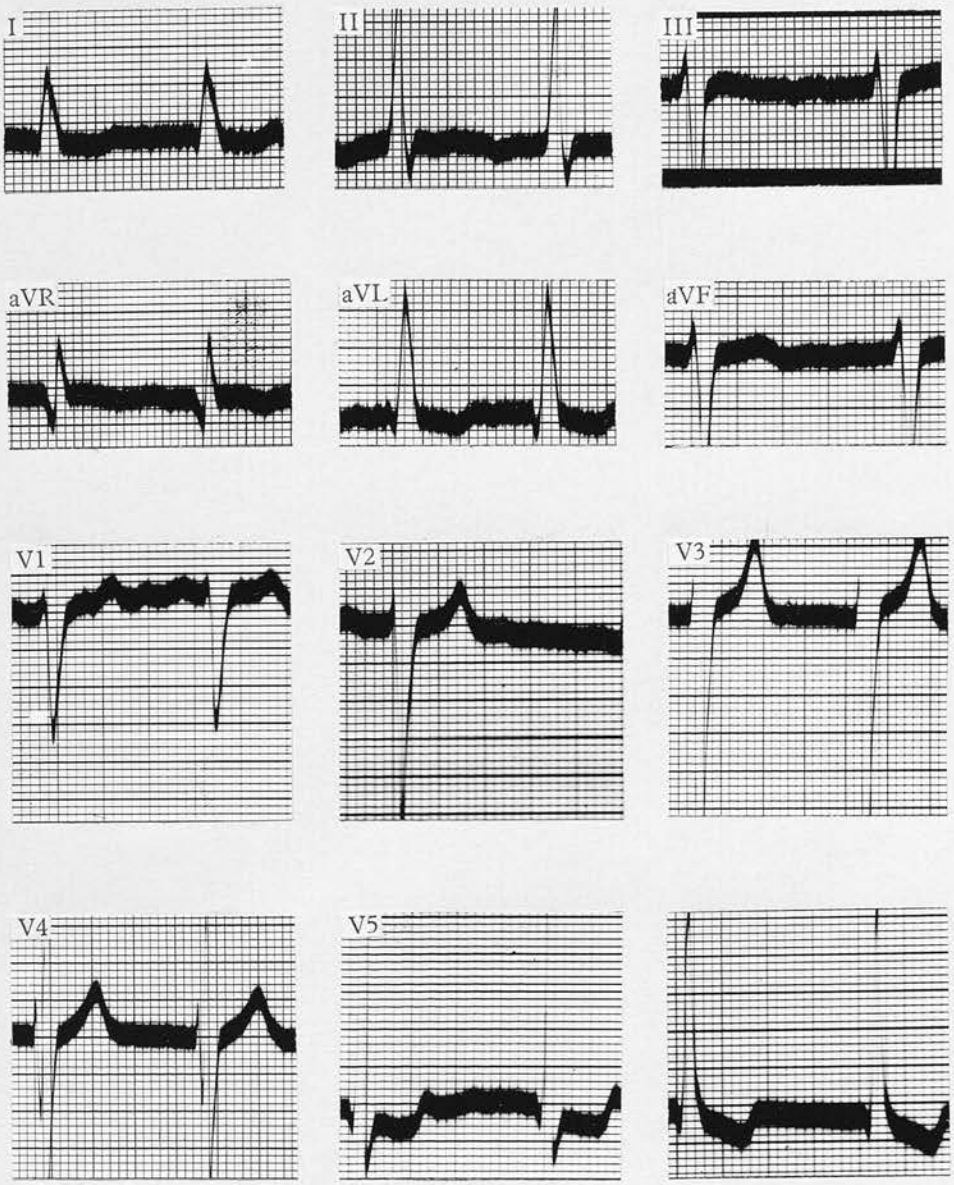


FIG. 53 Electrocardiogram of Case 71. Patent Ductus aged 64yrs. with Left Ventricular Hypertrophy.
Auricular Fibrillation
ST depression, diphasic T waves in I,aVL,V5,V6
No Digitalis immediately prior to Electrocardiogram

Case 45. J.S., female, 14yrs.

Stomal Patent Ductus

Gross signs of Patent Ductus with thrill propagated to suprasternal notch and Carotids.

Recanalisation after ligation.

Minimal signs for one year, with progressive improvement in X-ray and electrocardiographic appearances.

After two years, increasing signs of recanalisation.

History - Easily tired and breathless on exertion since 5yrs. Noise of heart audible after exertion.

Examination - Well below standard height and weight. Well-marked pulsation and thrill in suprasternal notch propagated to Carotids. Diastolic thrill and Gibson Murmur (IV) at Pulmonary area. Second sound markedly accentuated. Mitral mid-diastolic Murmur. Widespread systolic murmur over back. B.P. 135/45, after exercise 160/30.
X-ray - marked enlargement of cardiac shadow (Cardiac Area +52%) with well-marked enlargement of Pulmonary Artery and hilar vessels and increased vascularity of lung fields. Left Atrium enlarged. Screen examination showed increased pulsation in great vessels and a degree of hilar dance.
E.C.G. - signs of Left Ventricular Hypertrophy with ST depression and T inversion in standard and unipolar leads.

Operation - Ligation undertaken because of degree of disability. Stomal Ductus found which was ligated with difficulty. After ligation, no murmur or thrill. B.P.110/80. On 19th day, a faint diastolic murmur was heard, continuous after exercise. This murmur did not have the characteristic quality of the Gibson Murmur, but was high-pitched and blowing.

Follow-up - one month after operation, some decrease in size of heart (+32%) with disappearance of Left Atrial enlargement and no hilar dance.
One year after operation, much more fit, had gained 8lbs. in weight and could walk for miles. Continuous murmur remained, Grade I intensity. B.P. 115/80. Exercise test negative. Further decrease in heart size to +15% and reduction in depth of Q and in height of R waves in Left

precordial leads. Signs of Left Ventricular Hypertrophy minimal.
Two years after operation - continued improvement. Able for gym and Hockey. Further gain of one stone in weight. Thrill again palpable in suprasternal notch. Gibson Murmur a little more marked. B.P.115/64, Exercise test again positive. Some increase in cardiac size (+28%). Lung fields more congested and hilar dance reappeared. E.C.G. no change.

Figures 54 - 58 illustrate the X-ray and electrocardiographic appearances of Stomal Ductus before and after ligation.

1)

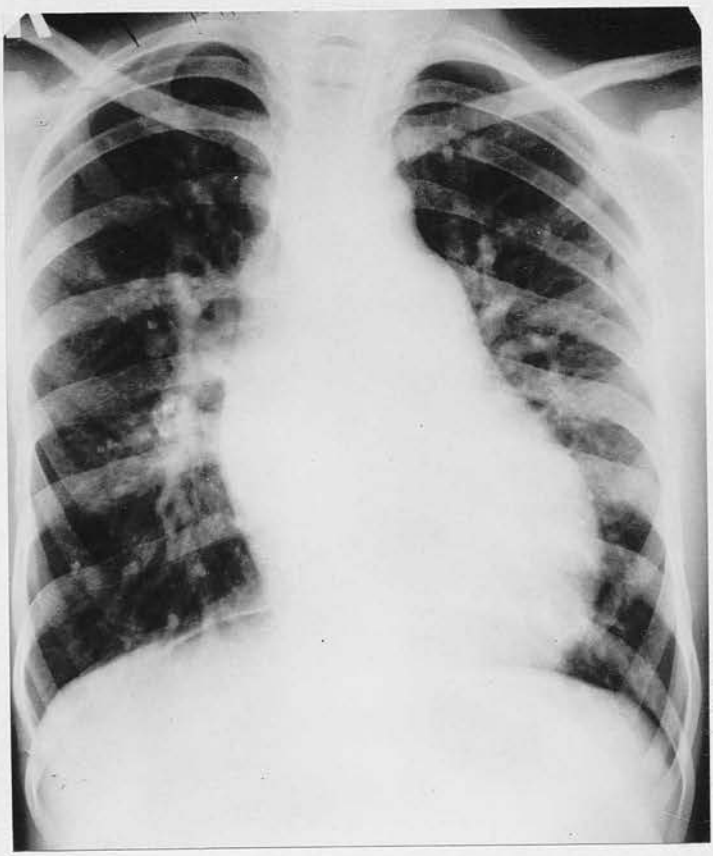
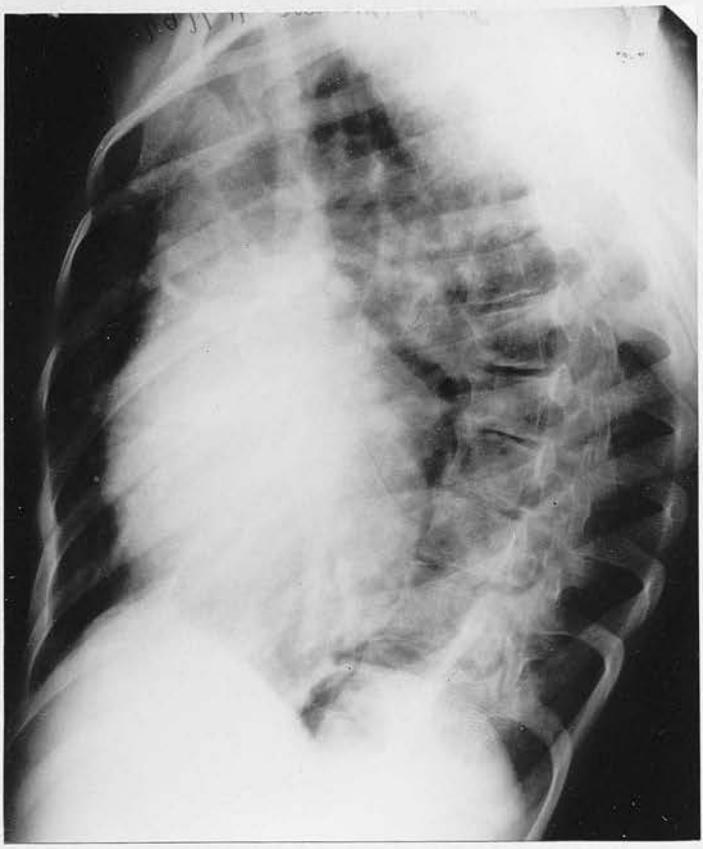


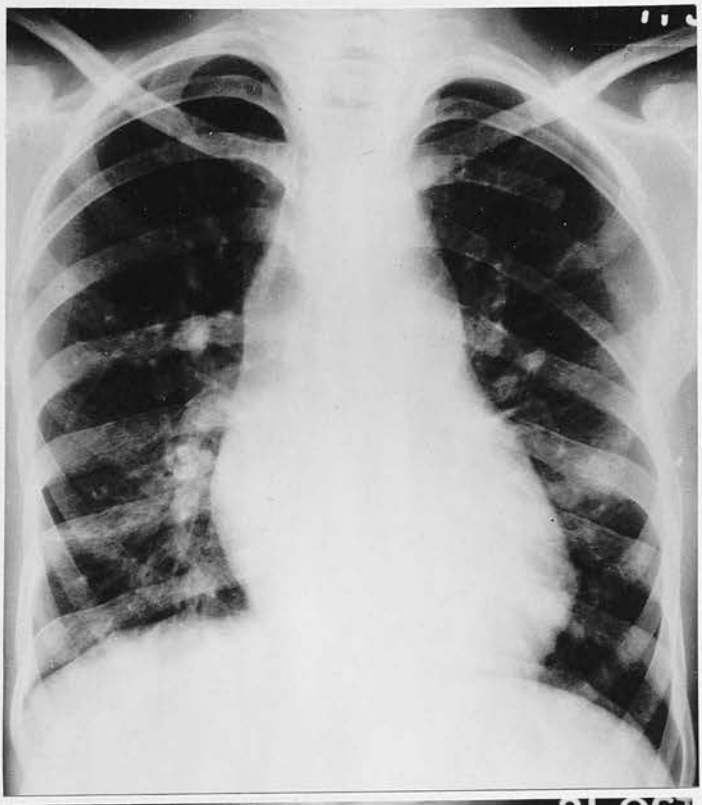
FIG. 54 Radiograph of Case 45. Stomal Ductus, with recanalisation after ligation.
1) P.A. 2) L.A.O. 3) R.A.O. before operation
Marked cardiac enlargement (C.A. +52%)
Enlargement of Pulmonary Artery and hilar vessels with hilar dance
Increased vascularity of lung fields
Enlargement of Left Atrium
Brisk pulsation on screen examination

2)



3)

1)



2)

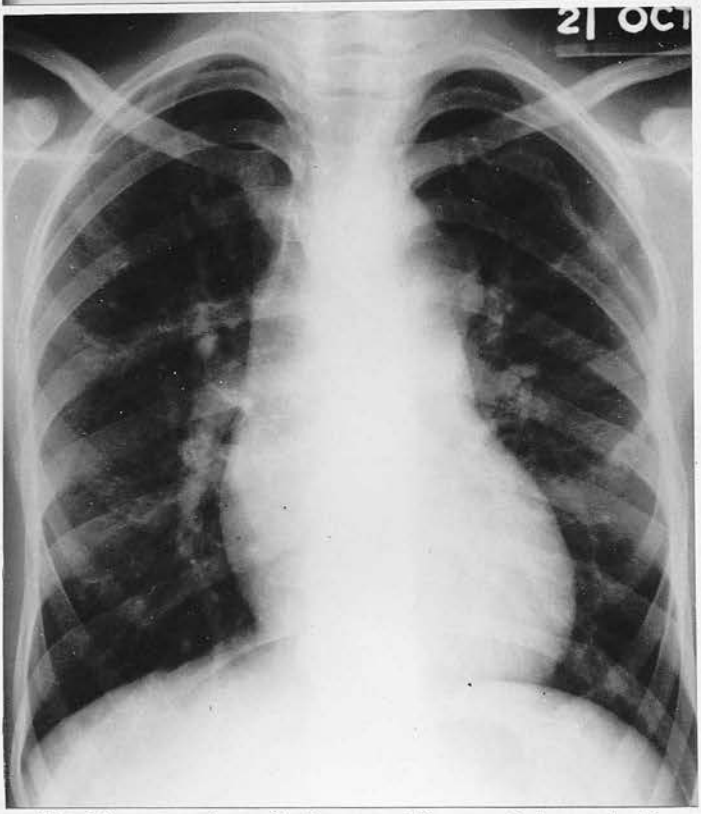


FIG. 55 Radiograph of Case 45. Stomal Ductus with recanalisation 19 days after ligation.
1) P.A. one month after ligation
2) P.A. one year after ligation
Decrease in size of cardiac shadow from +52% to +32% at one month and +15% at one year.
Increase in lung vascularity persists.
Pulmonary Artery remains prominent. Left Pulmonary Artery is unduly high.

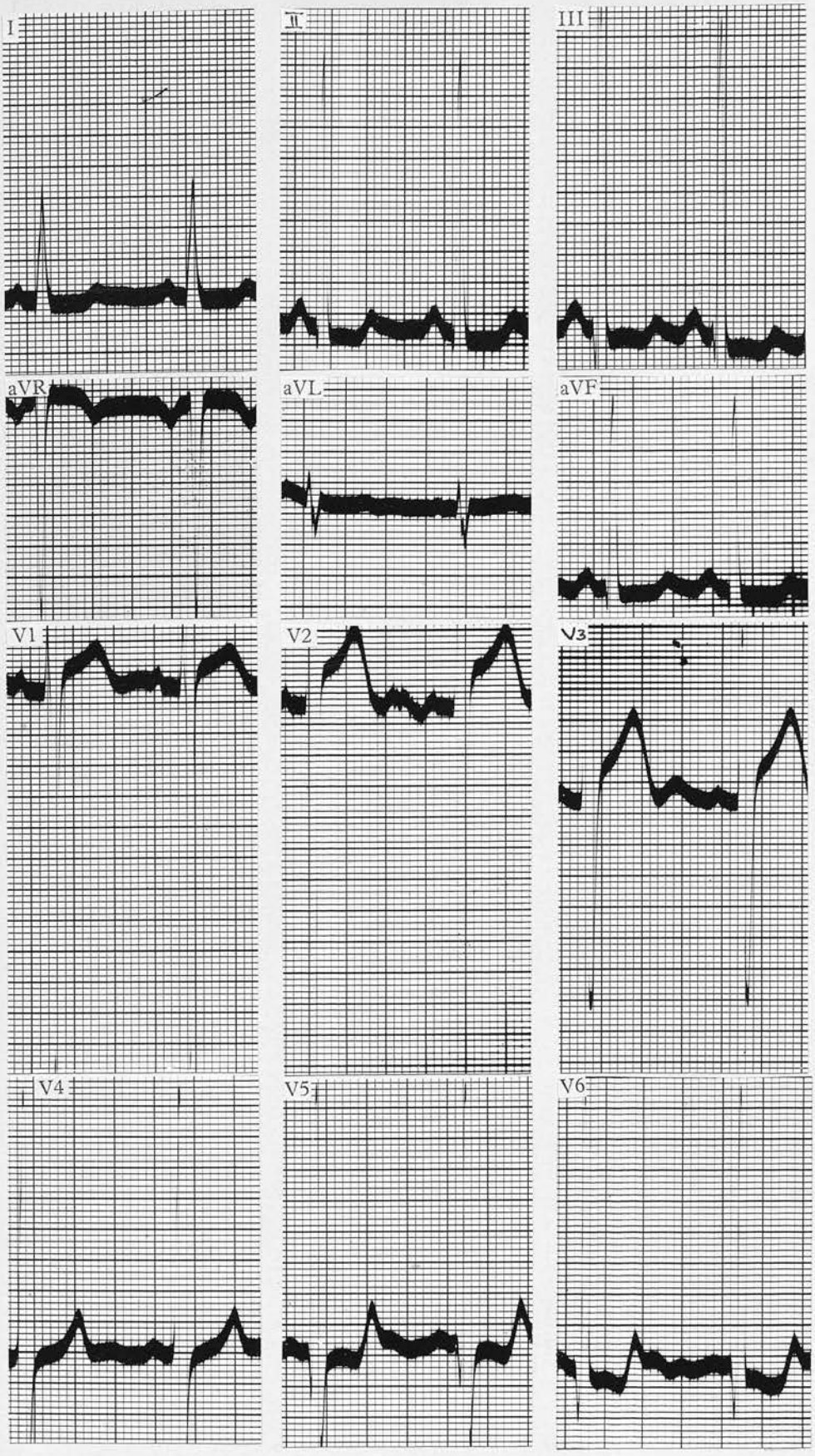


FIG. 56 Electrocardiogram of Case 45. Stomal Ductus aged 14yrs. Left Ventricular Hypertrophy.
Very high voltage in precordial leads
Deep Q, tall R waves V5, V6
ST depression and diphasic T waves
I, II, III, aVF and left precordial leads

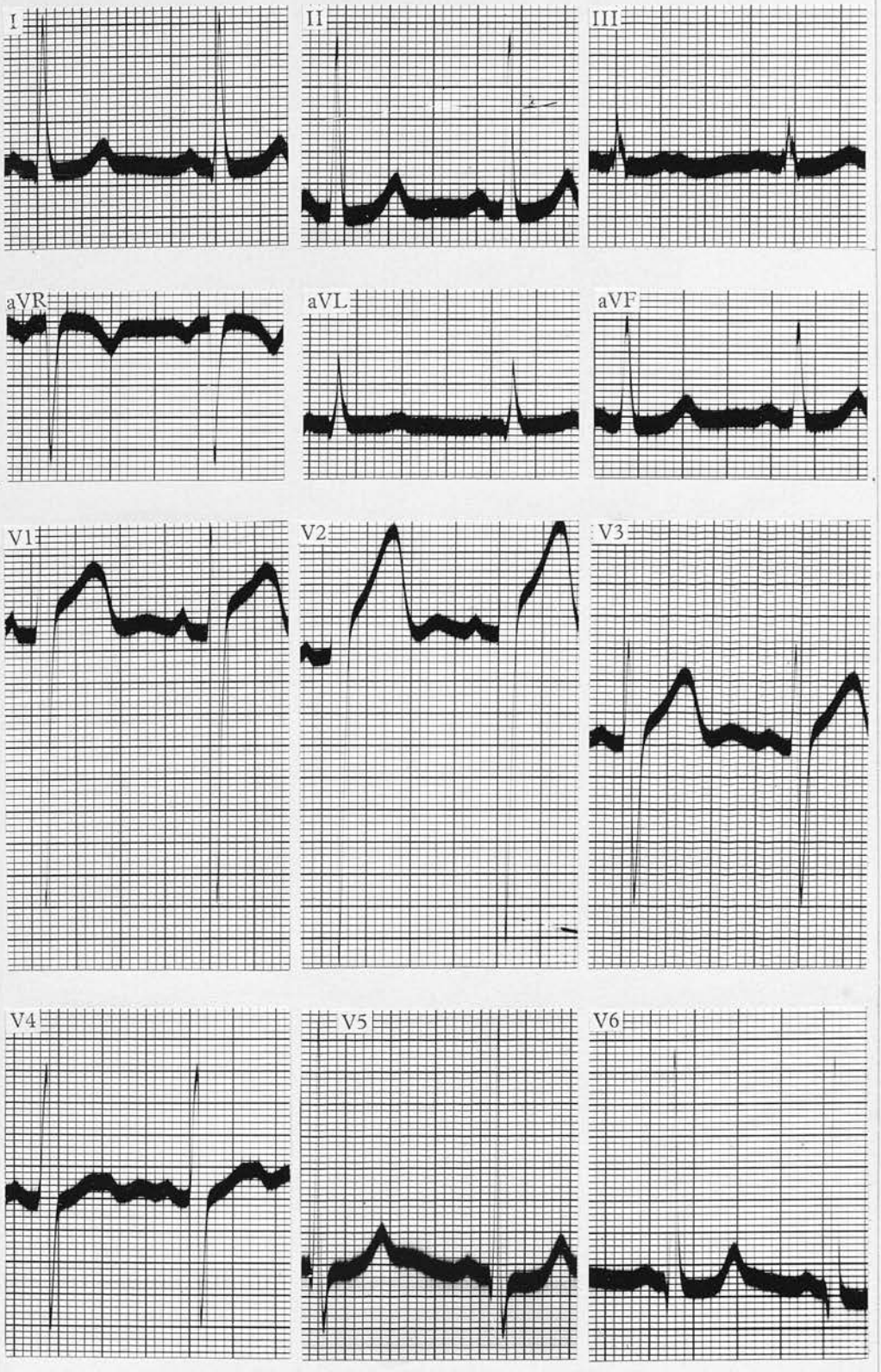


FIG. 57 Electrocardiogram of Case 45. Stomal Ductus four months after ligation (partial recanalisation).
Decrease in Voltage of precordial leads
Q waves much diminished V5, V6

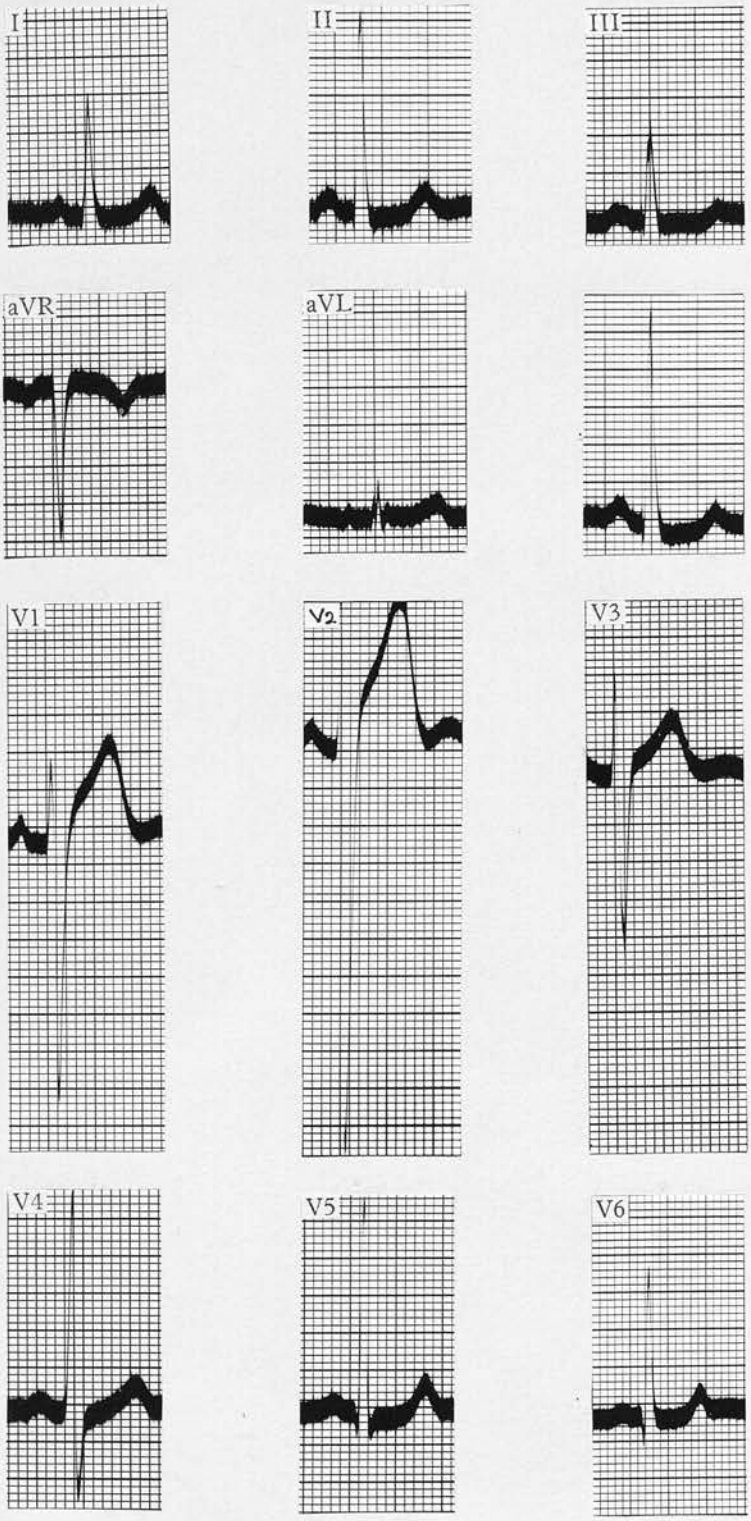


FIG. 58 Electrocardiogram of Case 45. Stomal Ductus one year after ligation (partial recanalisation).
Further decrease in Voltage of precordial leads
Signs of Left Ventricular Hypertrophy minimal in precordial and limb leads

Case 46, D.F., male, 7yrs.

Large Patent Ductus Arteriosus.

Partial Recanalisation after Ligation.

Development of calcifying, pulsatile shadow in region of Left Pulmonary Artery one year after Ligation.

History - Difficulty in feeding as a baby. Retarded development. Very easily tired and breathless on exertion, increasing from 4 years of age. Not able for competitive games.

Examination - Thin, poorly nourished. Well below standard height and weight. Visible pulsation in suprasternal notch. No thrills there or in Carotids as in Stomal Ductus. Marked systolic and diastolic thrills all over precordium. Thundering Gibson Murmur (IV). Second sound much accentuated and split. Long mid-diastolic murmur at apex. B.P. 115/55, after exercise 165/5.
X-ray - gross cardiac enlargement (+70%) affecting both Ventricles, enlargement of Pulmonary Artery and increased Hilar Vessels with Hilar Dance.
E.C.G. - High voltage. Deep Q and tall R waves left precordium. No definite evidence of Left Ventricular Hypertrophy.

Operation, aged 9yrs. - Very large, broad Ductus found, ligated with two silk ligatures. Return of diastolic murmur on seventh day, becoming continuous a few days later. No return of thrills. B.P.120/80.

Observation over two years has shown progressive improvement in capacity for exercise. Able for Cricket, Swimming and Fishing. Little improvement in nutrition.
Continuous murmur persists but is high-pitched and hollow-sounding, unlike ordinary Gibson Murmur. Second sound remains accentuated. No Mitral mid-diastolic murmur. No thrills. B.P.115/80 with negative exercise test after brisk exercise.
Heart size has continued to decrease (+70% before operation, +40% one year after, +30% two years after). Pulsation on screen is within normal limits and does not suggest Patency of the Ductus.
Pulsatile swelling noticed in region of Left Pulmonary Artery one year after operation, and is now calcifying. ?Left Pulmonary Artery higher than usual. ?Small aneurysm in Pulmonary end of ligated Ductus
E.C.G. - after initial appearance suggesting Left Ventricular Hypertrophy one month after operation, has shown progressive decrease in voltage.

1)

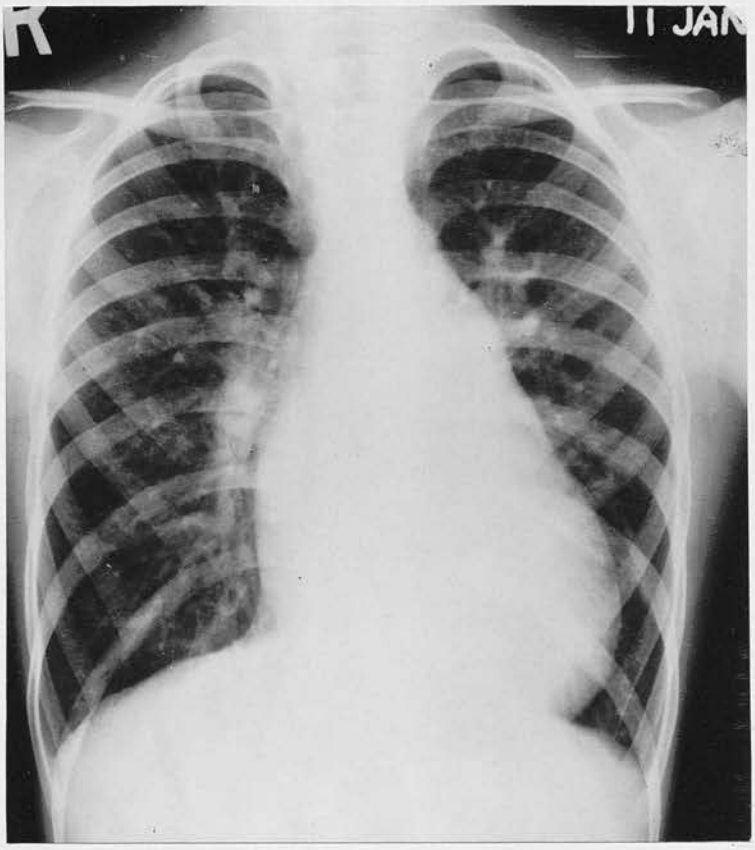
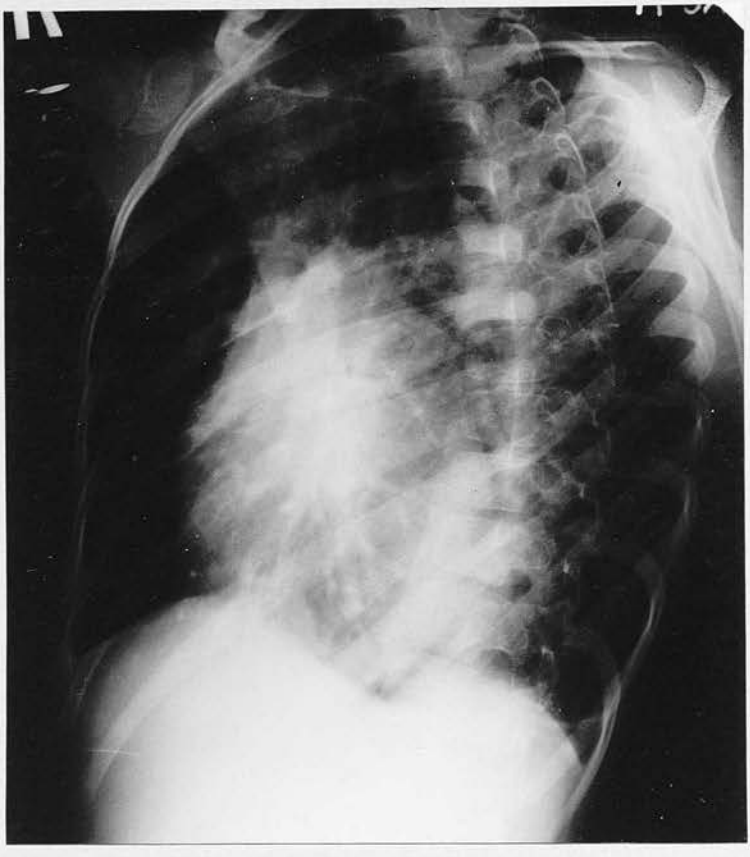
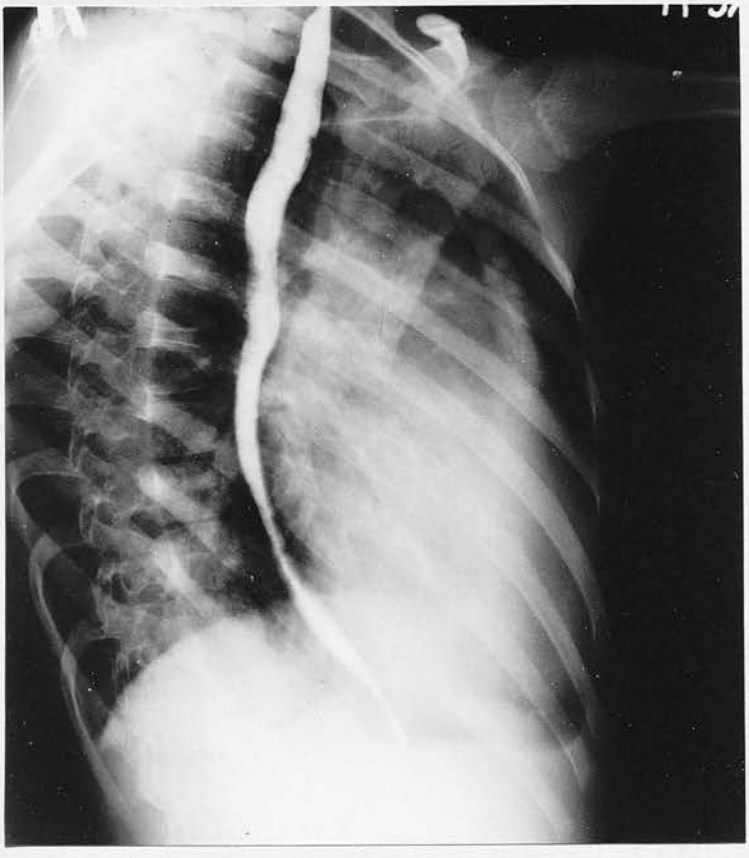


FIG. 59 Radiograph of Case 46. Large Patent Ductus aged 9yrs.
1) P.A. 2) L.A.O. 3) R.A.O. before ligation
Gross cardiac enlargement (C.A. +70%)
Enlargement of Pulmonary Artery and hilar vessels with hilar dance.
Left Atrial enlargement
Brisk pulsation on screen examination

2)



3)



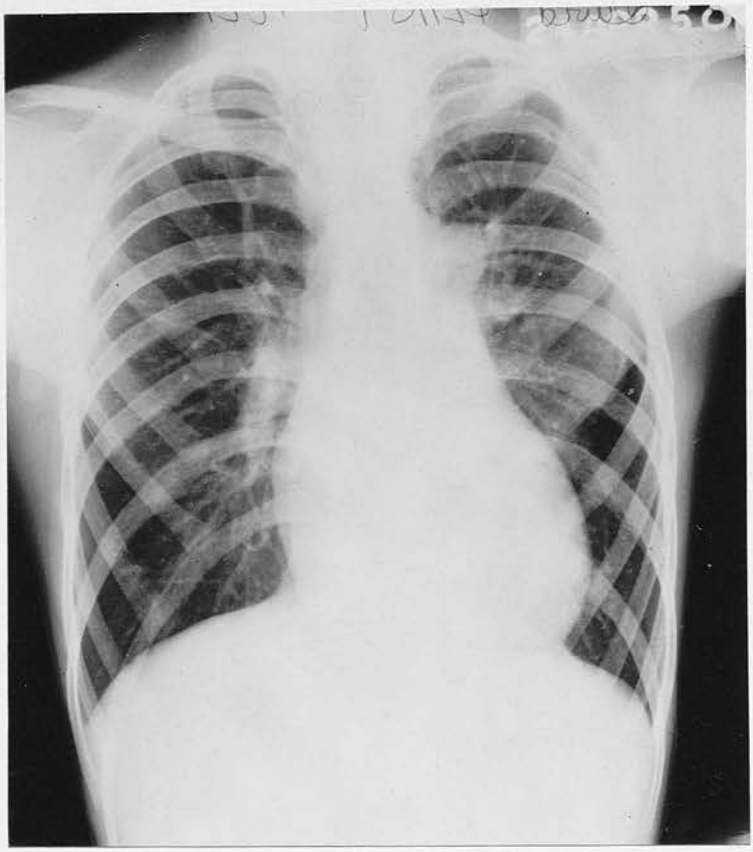
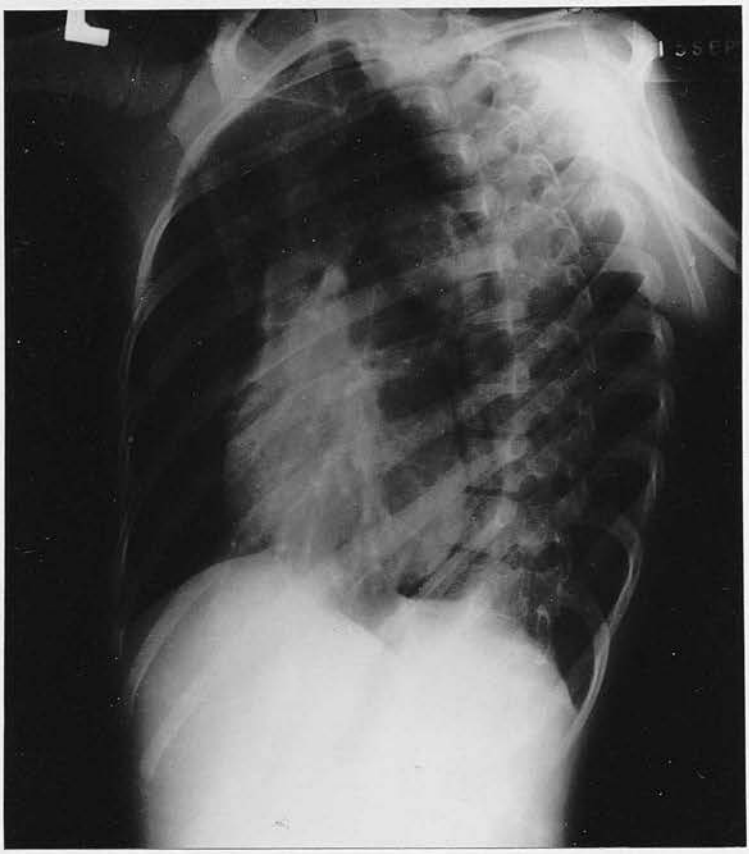


FIG. 60 Radiograph of Case 46. Large Patent Ductus with recanalisation after ligation. Development of ?Pulmonary Artery Aneurysm.
P.A. one year after ligation.
Some decrease in cardiac size (C.A. +42%)
Localised bulge of cardiovascular shadow on left side below Aorta with slight expansile pulsation? Left Pulmonary Artery unusually high
Screen examination otherwise normal.

1)

FIG. 61 Radiograph of Case 46. Large Patent Ductus with recanalisation after ligation. Development of ?Pulmonary Artery Aneurysm.
1) P.A. 2) L.A.O. 3) R.A.O. 1½yrs.after ligation
Further decrease in cardiac size (C.A. +30%)
Decrease in size of Left Atrium.
Shadow remains in region of Left Pulmonary Artery and now shows calcification.
Screen examination otherwise normal.

2)



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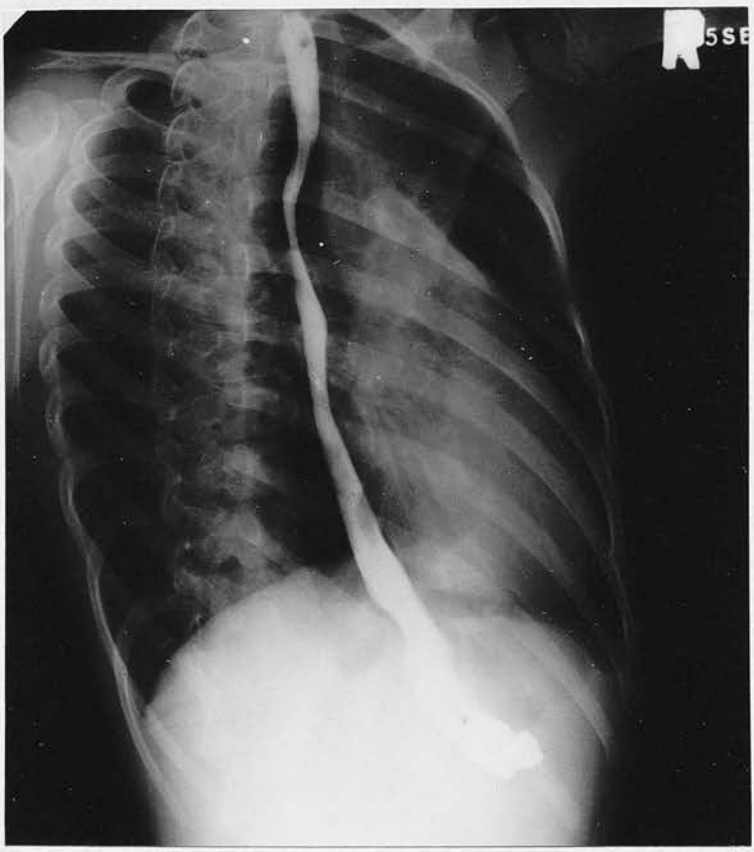


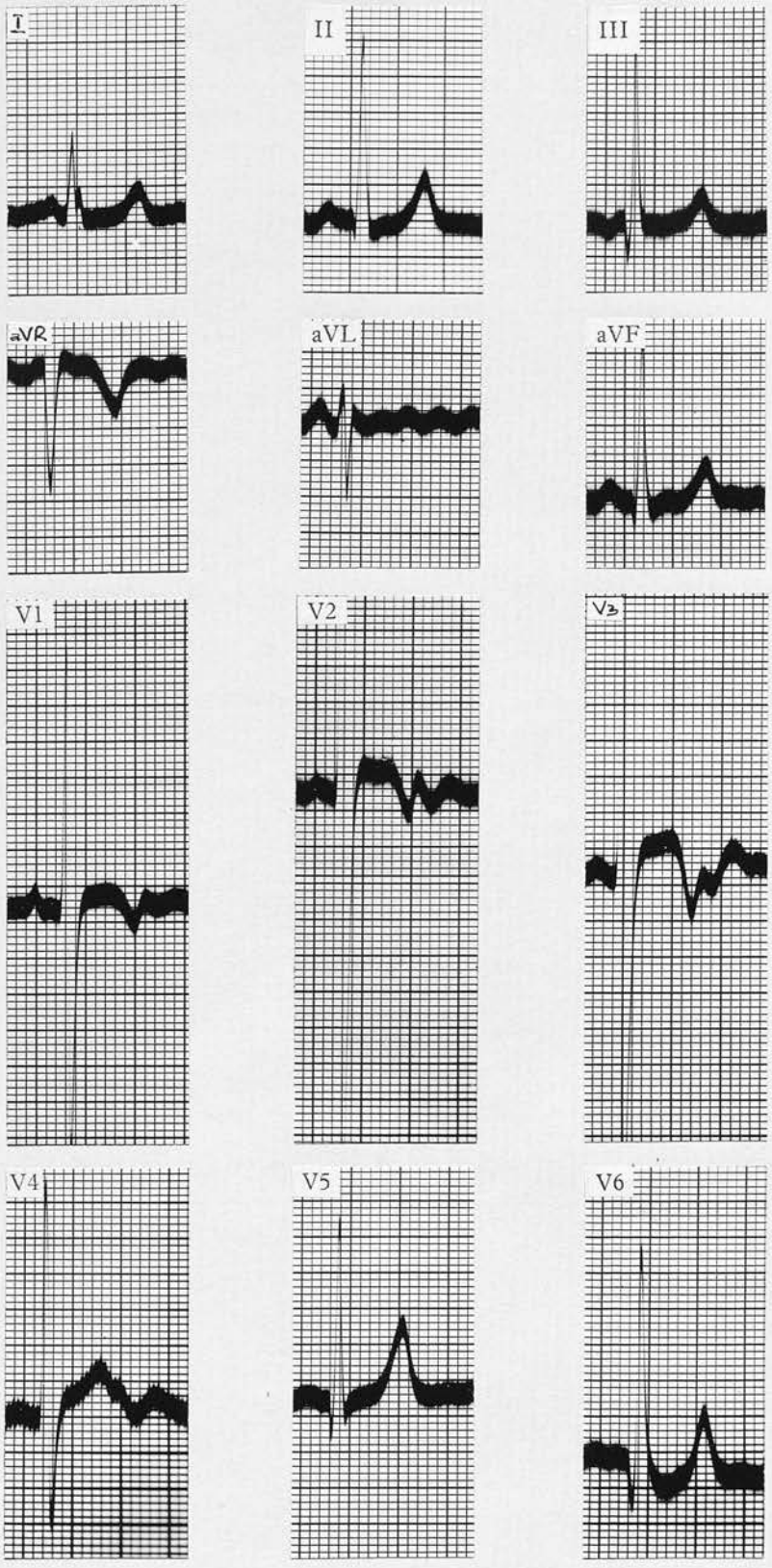


FIG. 62 Electrocardiogram of Case 46. Large Patent Ductus aged 9yrs. High voltage in precordial leads. Deep Q and tall R waves over left precordium Marked notching of T waves in precordial leads

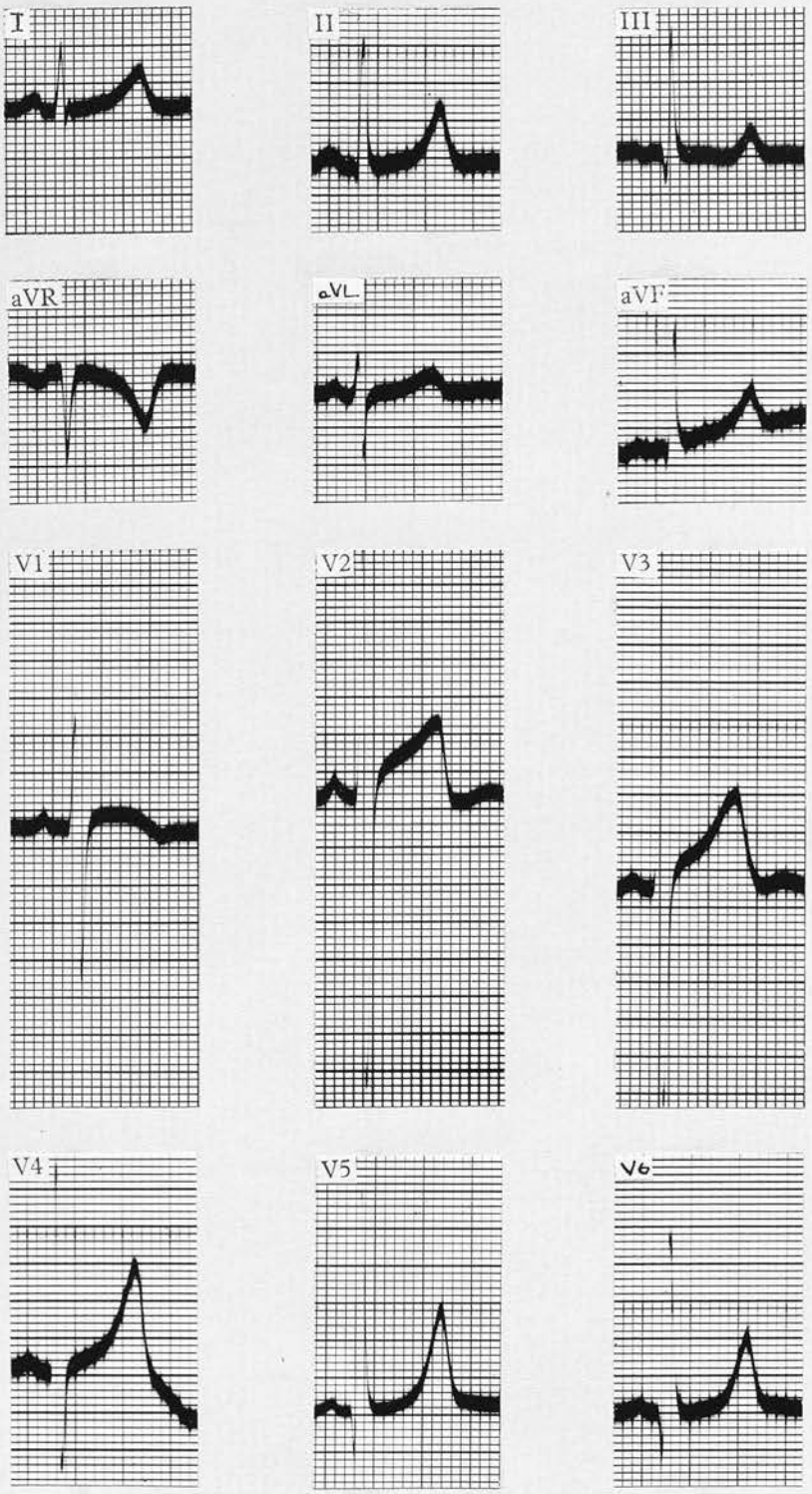


FIG. 63 Electrocardiogram of Case 46. Large Patent Ductus with recanalisation after ligation.
Little change in voltage 1½yrs. after ligation
Notching of T waves in precordial leads has disappeared.

Case 58. S.W., female, 5yrs.

Large Patent Ductus.

Development of Periductal Haematoma three months after successful ligation.

Pathological appearance of Ductus four months after ligation.

History - First seen aged 5yrs. - easily tired and slightly breathless on exertion. Frequent attacks of severe respiratory infection. An only child; Mother had febrile illness, "Influenza", when four months pregnant.

Examination - A very fragile child, well below standard height and weight. Systolic thrill over the precordium, maximal in second and third spaces close to Sternum. Loud Gibson Murmur (III) heard widely, but maximal in second space associated with much accentuated and split second sound.
B.P.126/40 (Rt. arm), 105/40 (Left arm). Exercise test easily positive.
X-ray - marked cardiac enlargement (+40%) with much more right-sided enlargement than normal. Prominent Pulmonary Artery, with marked increase in vascularity of lung fields. Left Atrium enlarged. No hilar dance.
E.C.G. - deep Q waves and high voltage in left precordial leads, otherwise normal.

Operation advised because of severe recurrent respiratory infections and disability. Signs suggested large shunt present. Considerable dilatation of Pulmonary Artery found, overlying Ductus. The latter was short and broad and was ligated with two silk ligatures. Immediate rise in diastolic pressure satisfactory. No post-operative effusion or collapse.

Progress - One month after ligation, soft Pulmonary Systolic Murmur followed by accentuated second sound. B.P.120/80.
X-ray - immediate reduction in heart size (+20%), associated with signs of Left Ventricular Hypertrophy in E.C.G. Thereafter well and much more fit than ever before, until three months after operation, when she developed a cold followed by recurrent haemoptyses (bright red frothy blood).

Four months after operation, heart sounds much less forcible. No murmurs. Second sound only slightly accentuated. B.P.120/80. Signs of collapse left upper lobe.
X-ray - little further change in heart size and appearance. Non-pulsatile shadow in region of

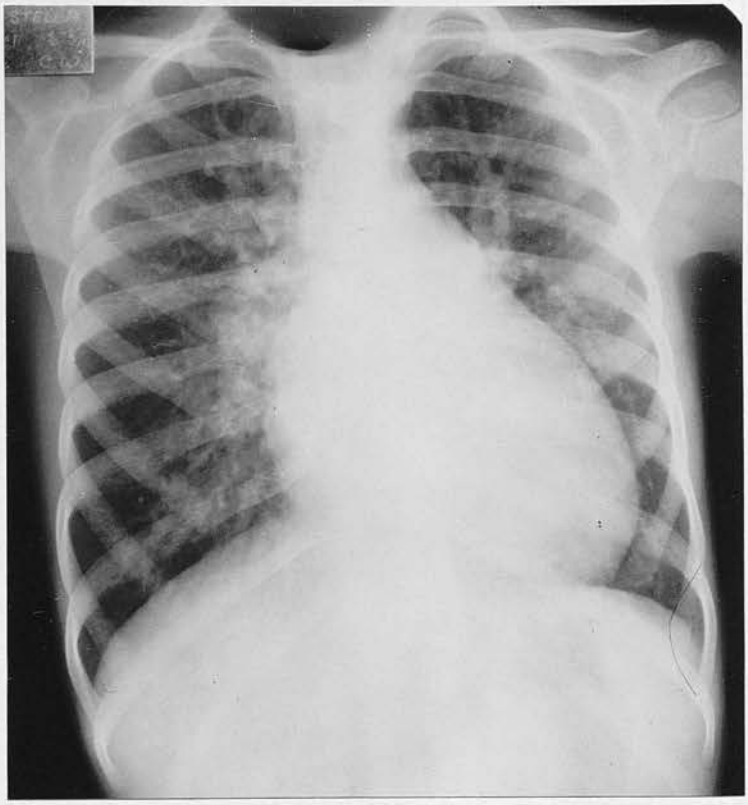
Pulmonary Artery. No evidence of infection.

Operation advised because of recurrent haemoptysis. Aorto-Bronchial Fistula considered. At operation, laminated clot surrounding the Ductus found. Severe haemorrhage occurred when this was dissected with death on the table.

Autopsy - Laminated clot around the ligated Ductus. No evidence of infection. No Fistula between Aorta and Lung. Ductus obliterated. Most of its muscle coat replaced by dense hyaline connective tissue. Intima showed marked endarteritis with layer upon layer of connective tissue.
First event would appear to have been development of Haematoma at site of operation, probably originally small, but growing by repeated haemorrhages from friable granulation tissue. The "cold" may have marked the onset of infection in the already collapsed upper lobe, with resultant haemoptysis.

Figures 64 - 69 illustrate the X-ray and Electrocardiographic appearances of large Ductus before ligation, with subsequent development of Periductal Haematoma.

1)



2)

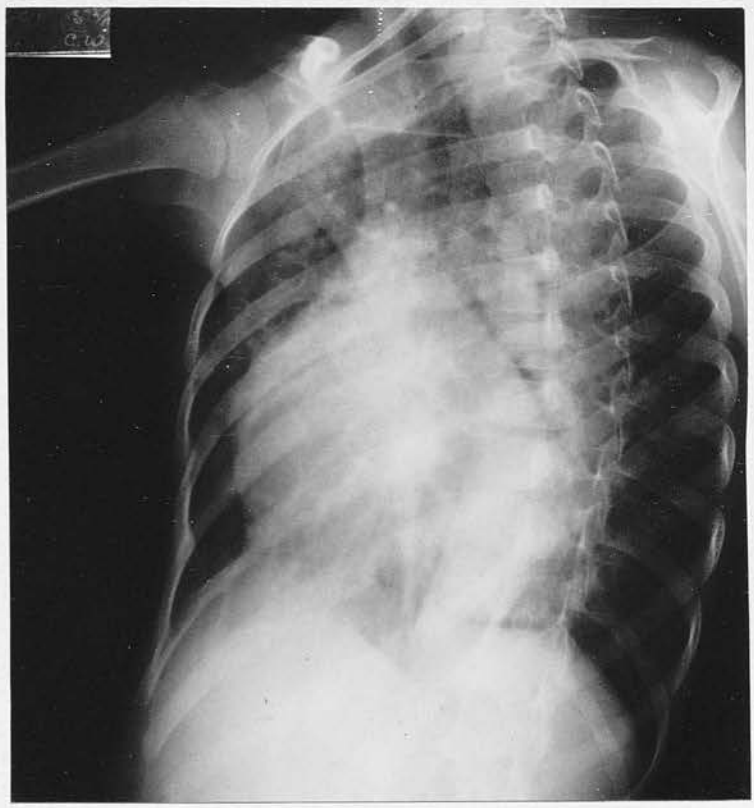
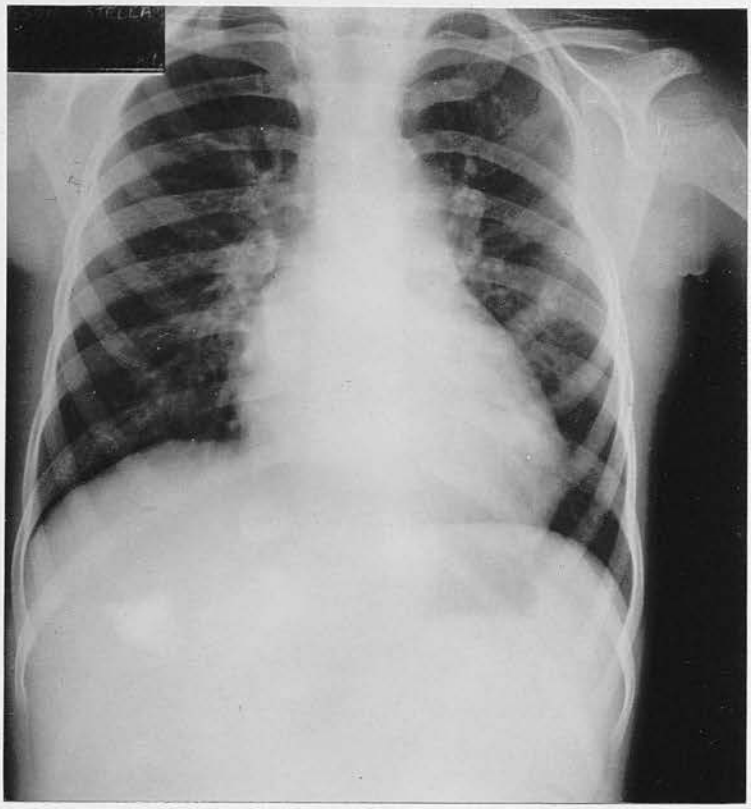


FIG. 64 Radiograph of Case 58. Very large Ductus aged 5yrs., with atypical appearance.
1) P.A. 2) L.A.O. prior to ligation.
Marked cardiac enlargement (+40%) with more right-sided enlargement than usual. Left oblique view not typical of Patent Ductus.
Large Pulmonary Artery and hilar vessels showing expansile pulsation on screen.
Gross congestion of lung fields.

1)



2)

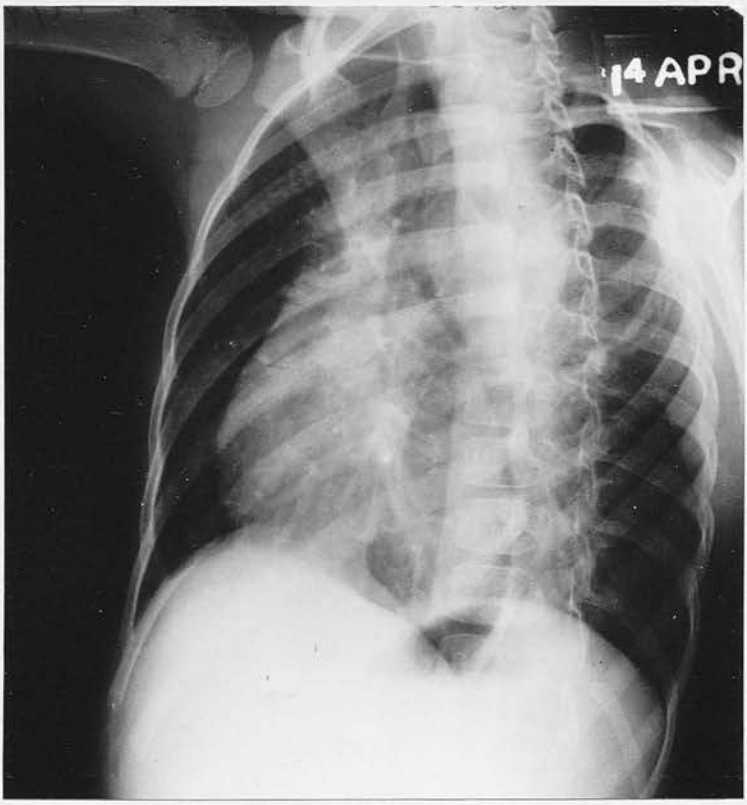


FIG. 65 Radiograph of Case 58. Very large Ductus with marked improvement 3 weeks after ligation.
1) P.A. 2) L.A.O. 3 weeks after ligation.
Reduction in cardiac size from +40% to +25%
Diminution in right-sided enlargement and in Pulmonary congestion

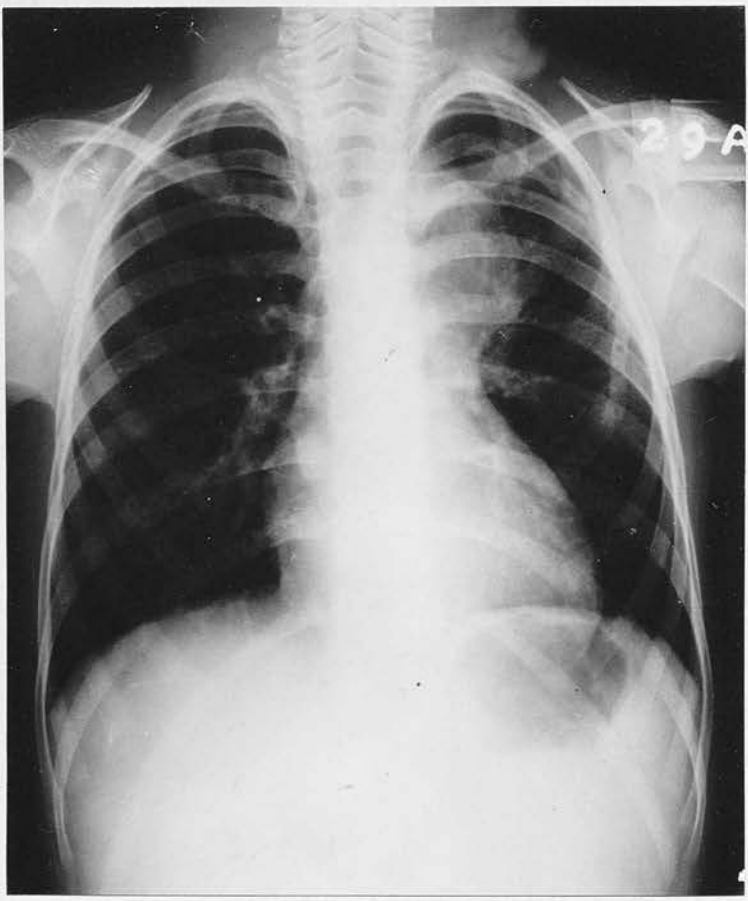


FIG. 66 Radiograph of Case 58. Large Ductus with development of Periductal Haematoma four months after successful ligation.

P.A. four months after ligation
Further decrease in cardiac size (C.A.+20%)
Development of non-pulsatile shadow in region of ligated Ductus - proved at operation to be Periductal Haematoma.

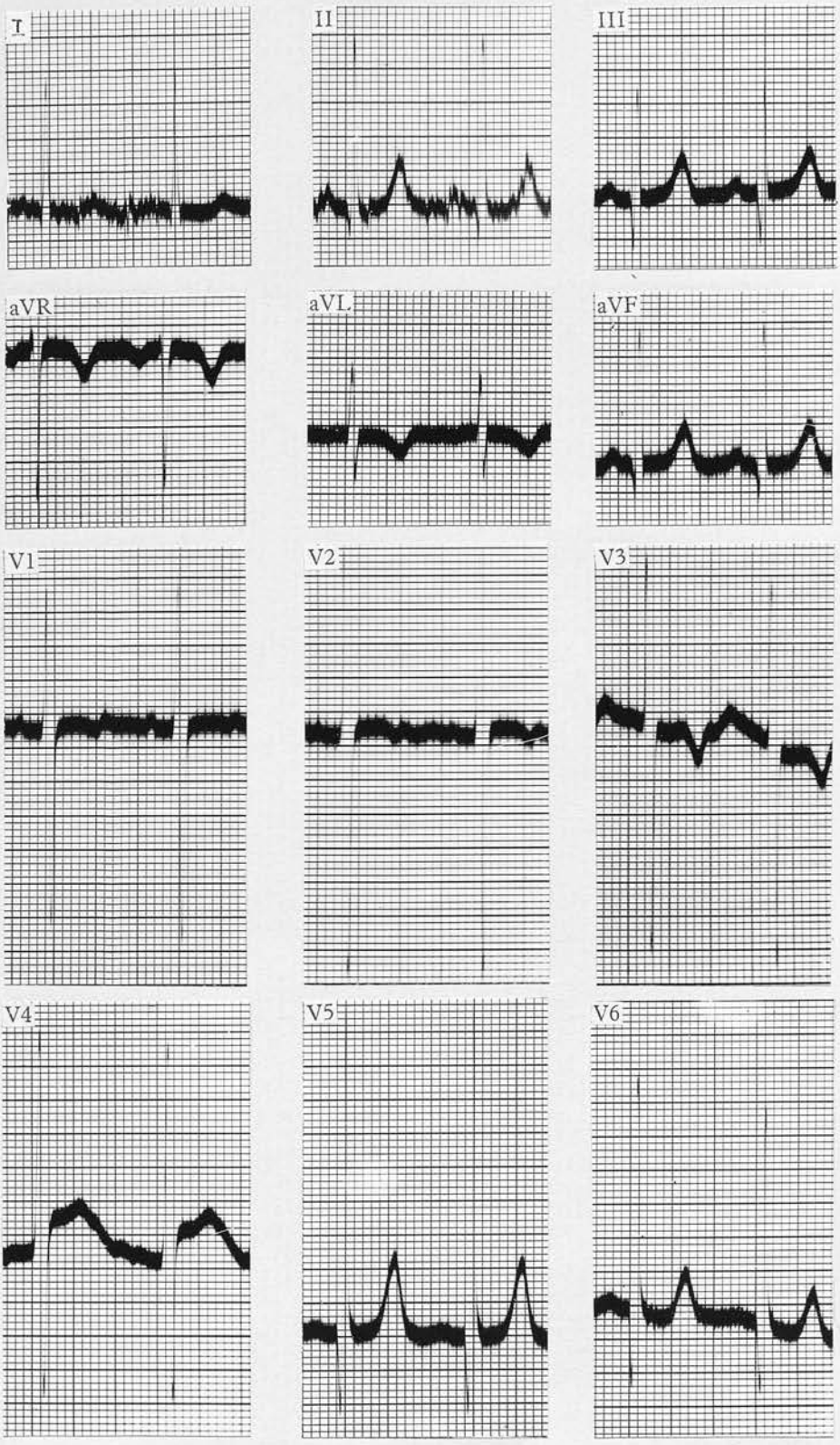


FIG. 67 Electrocardiogram of Case 58. Large Ductus aged 5yrs. Very High Voltage in precordial leads.
V1, V2, V3 - half sensitivity
Deep Q and tall R waves in Left Precordial Leads
No other evidence of Left Ventricular Hypertrophy

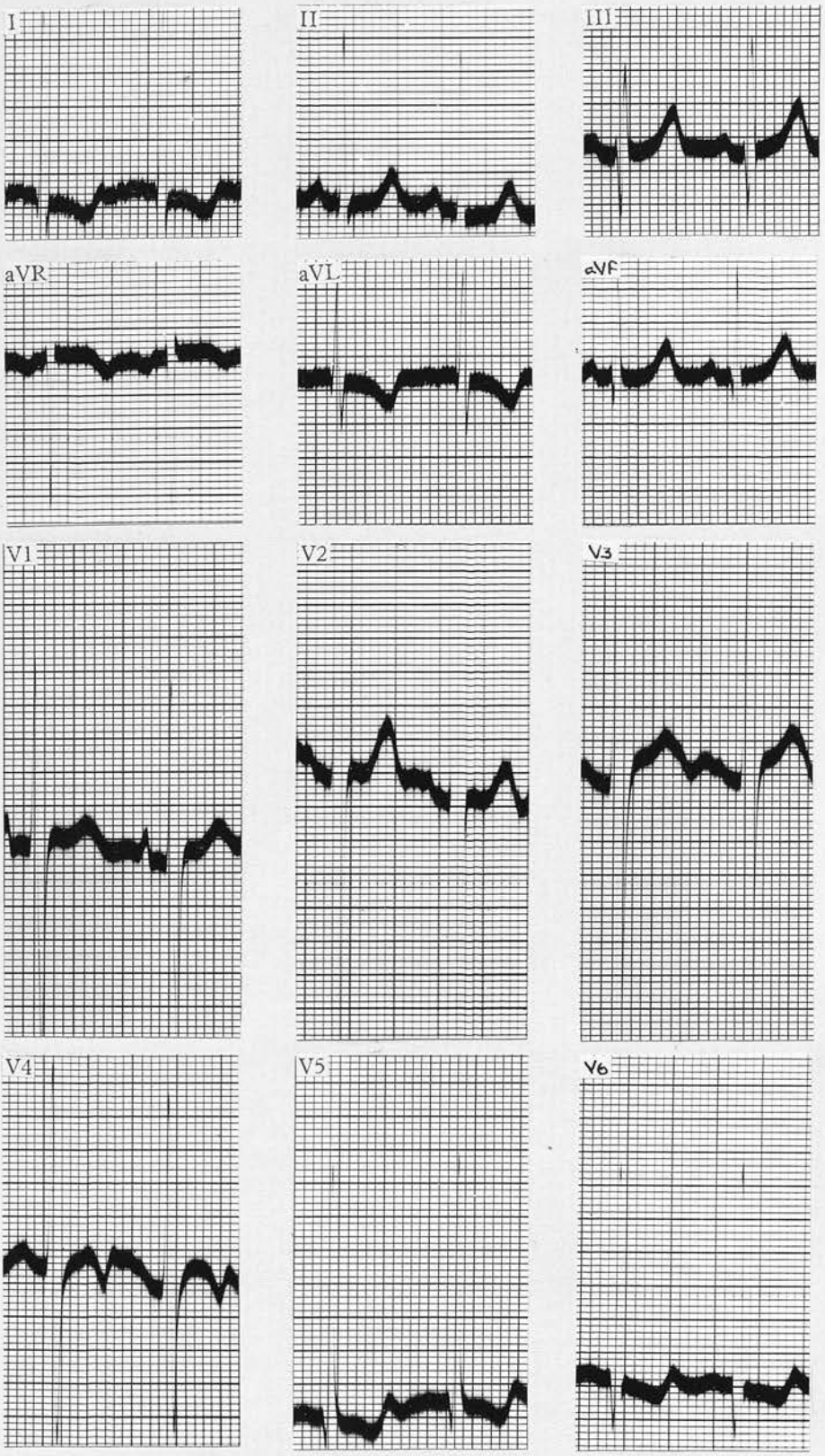


FIG. 68 Electrocardiogram of Case 58. Large Ductus with appearances suggesting Left Ventricular Hypertrophy two weeks after ligation.
Marked diminution in voltage of precordial leads. ST depression and diphasic T waves in I, aVL, V5, V6.

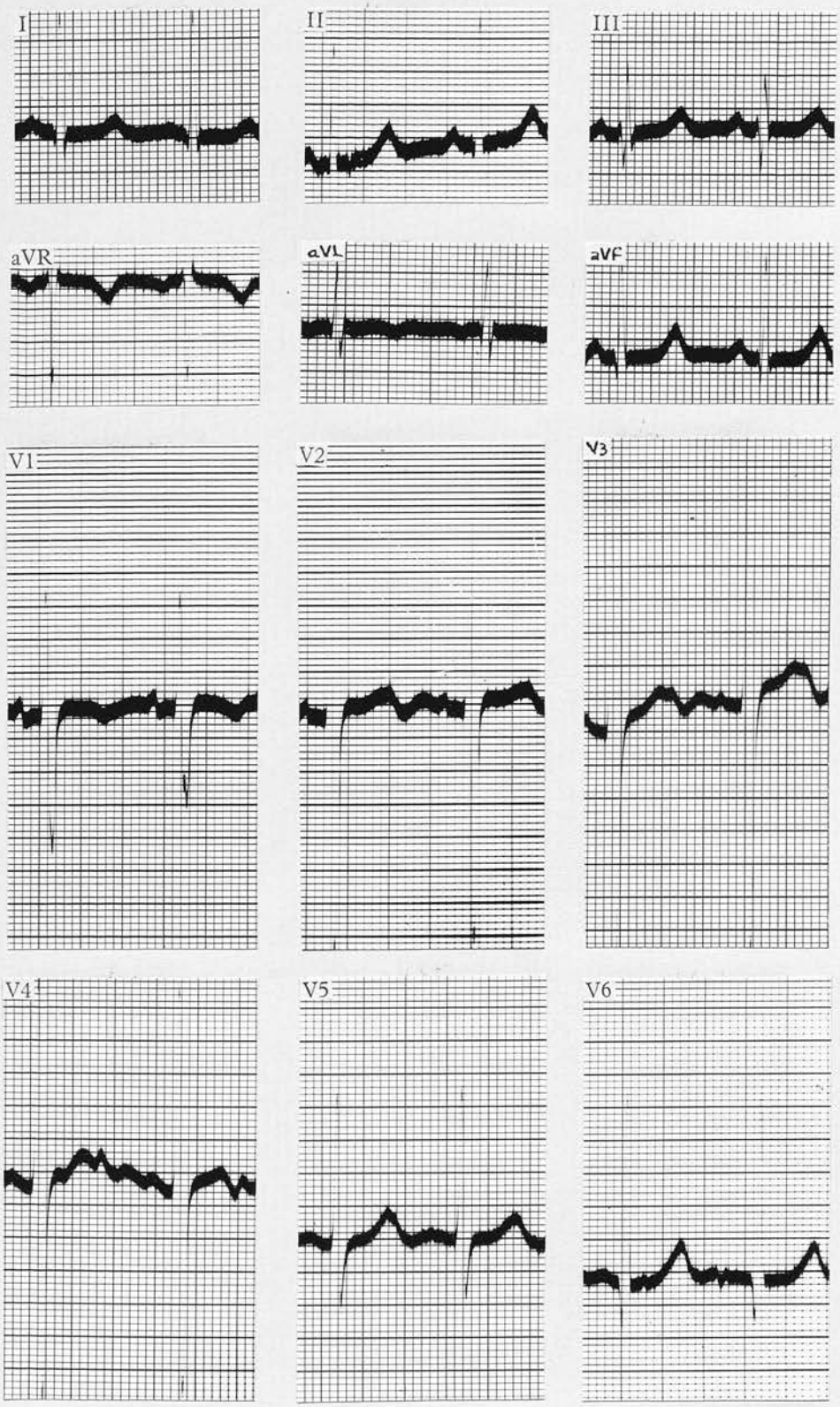


FIG. 69 Electrocardiogram of Case 58. Large Ductus, four months after ligation. Normal Electrocardiogram.
Further reduction in voltage of precordial leads.
Disappearance of deep Q waves.
Disappearance of ST.T changes seen immediately after ligation.

Case 39. J.McK., female, 7yrs.

Patent Ductus associated with Deaf-Mutism following Rubella in Pregnancy.

Infective Pulmonary Endarteritis due to Haemolytic Staphylococcus Aureus.

Infection controlled by Penicillin.

Development of Pulmonary Artery Aneurysm.

Resolution after Ligation of Patent Ductus.

History - Always backward and slow to develop. Deaf and dumb from birth. Mother had German Measles when one month pregnant. Measles two months before admission, with dysphagia, cough and fever thereafter.

Examination - Extremely ill when first seen with gross signs of Patent Ductus, widespread thrill, Gibson Murmur (IV) heard all over precorium with very marked diastolic component down left border of Sternum. B.P.100-110/20. Mild congestive failure, finger and toe clubbing developing rapidly. Blood Cultures (2) - Haemolytic Staphylococcus Aureus.
X-ray - unusual degree of cardiac enlargement (Cardiac Area +66%). Upper mediastinal shadow enlarged to left, probably mainly due to enlarged Pulmonary Artery, but opacity extending to higher level.
E.C.G. - at this time suggested Left Ventricular Hypertrophy with deep Q waves and very tall R waves in V5, V6. T inversions across precordium were probably due to recent Pulmonary Infarction.

Progress - Rapid improvement on Penicillin, 600,000 units daily, apart from one Pulmonary Infarct five days after start of therapy.
Following control of infection by Penicillin, progressive improvement in general condition and some diminution in heart size. Physical signs remained unchanged - Systolic and diastolic thrills and very loud Gibson Murmur (IV) heard all over precordium. Three months after, X-ray showed increase in size of supracardiac shadow, this shadow being pulsatile.

Operation advised. Aneurysmal swelling of Pulmonary Artery found. Ligation of Ductus carried out in the hope that reduction in Pulmonary Pressure would allow resolution of Aneurysm.

Progress after ligation - no residual murmurs or thrills. B.P. 90/80. Pulse Pressure remained

very low for two years. B.P. now 104/70.
Exercise Test negative.
X-ray - progressive decrease in size of heart, one month after +26%, three months after +22%, two years after +14%, and associated with this, decrease in size of Pulmonary Artery. No increased pulsation now over heart or great vessels.
E.C.G. - after initial increase in signs of Left Ventricular Hypertrophy for three months after operation, has shown steady reduction in voltage and is now normal.

Figures 70 - 76 illustrate the X-ray appearances during the development and resolution of the Pulmonary Artery Aneurysm, the general appearance of the child and the electrocardiographic changes before and after operation.

1)

2)

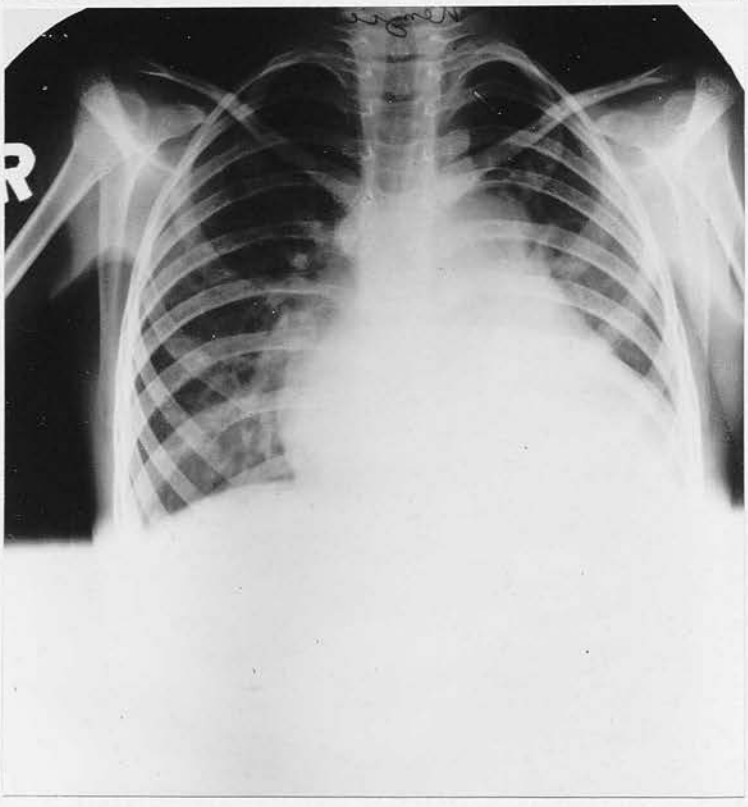
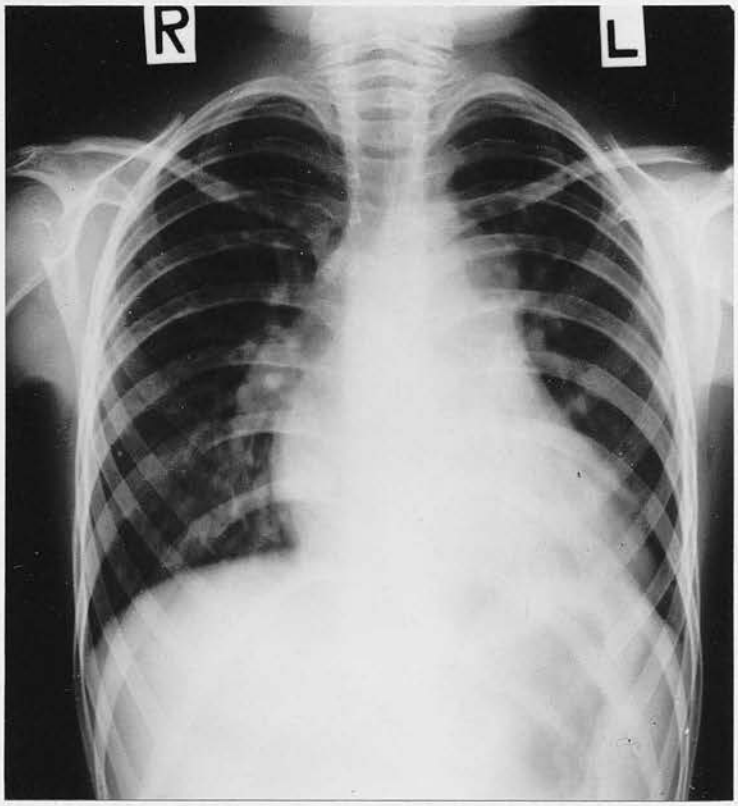


FIG. 70 Radiograph of Case 39. Patent Ductus Arteriosus with Pulmonary Endarteritis aged 7yrs.
1) P.A. at onset of illness 2) P.A. 2 weeks later
Cardiac enlargement (+60%)
Pulmonary infarction Left base
Pulmonary Artery and Aorta not clearly distinguishable.

1)



2)

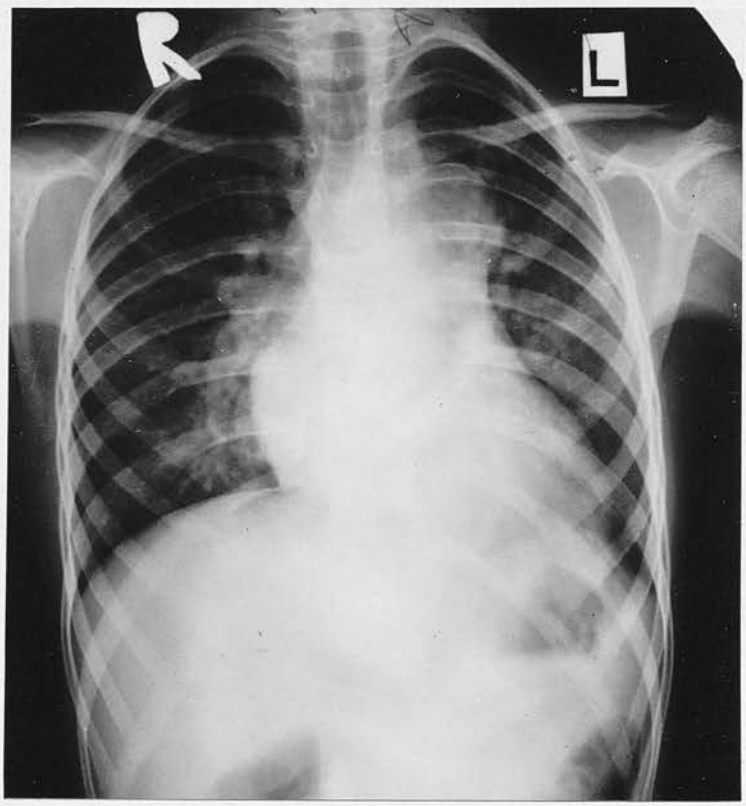
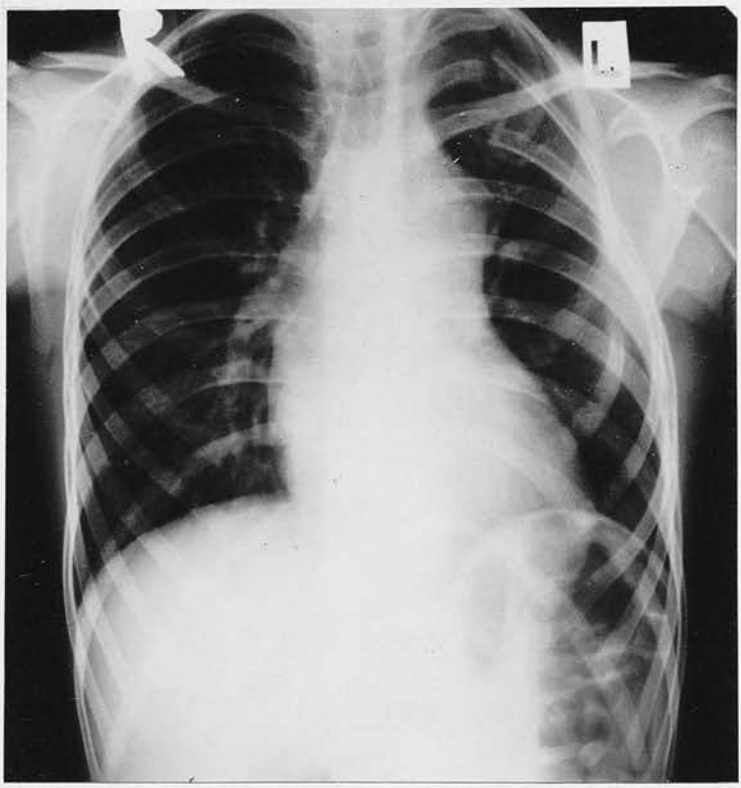


FIG. 71 Radiograph of Case 39. Infected Patent Ductus with development of Pulmonary Aneurysm.
1) P.A. one month after onset of illness.
2) P.A. four months after onset of illness.
Infection controlled.
Reduction in cardiac size (C.A. +44%)
Pulsatile swelling in region of Pulmonary Artery.

1)



2)

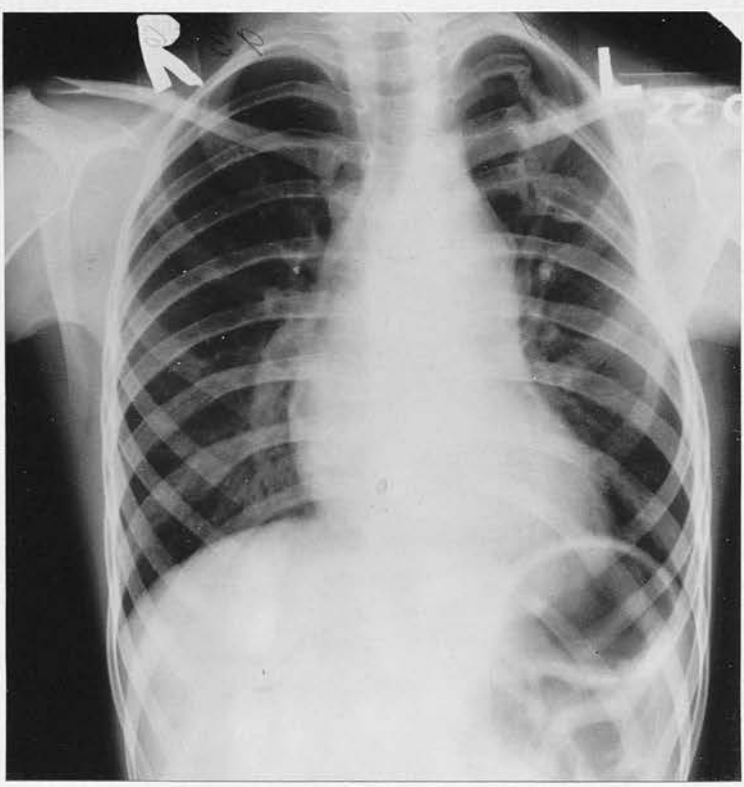
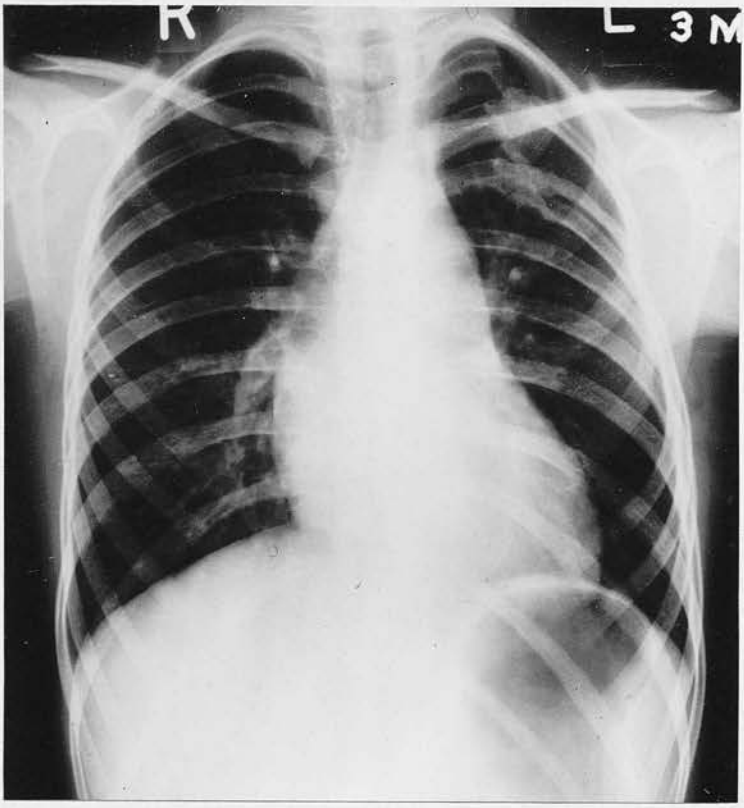


FIG. 72 Radiograph of Case 39. Pulmonary Aneurysm following Infected Patent Ductus; immediately after ligation of Patent Ductus Arteriosus.
1) P.A. one month after ligation.
Reduction in cardiac size and in size of Pulmonary Artery.
2) P.A. three months after ligation.
Further reduction in cardiac size (C.A.+12%) and in Pulmonary Artery.

1)



2)

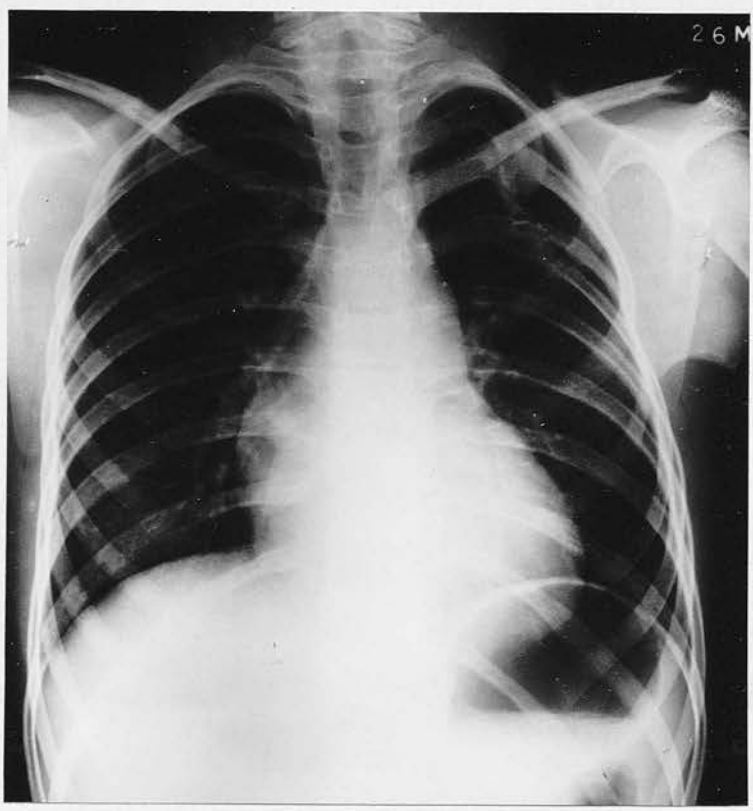


FIG. 73 Radiograph of Case 39. Pulmonary Aneurysm. Further follow-up.

1) P.A. one year after ligation.
2) P.A. two years after ligation.

No change in cardiac size
Further reduction in size of Pulmonary Artery
No increased pulsation on screen.

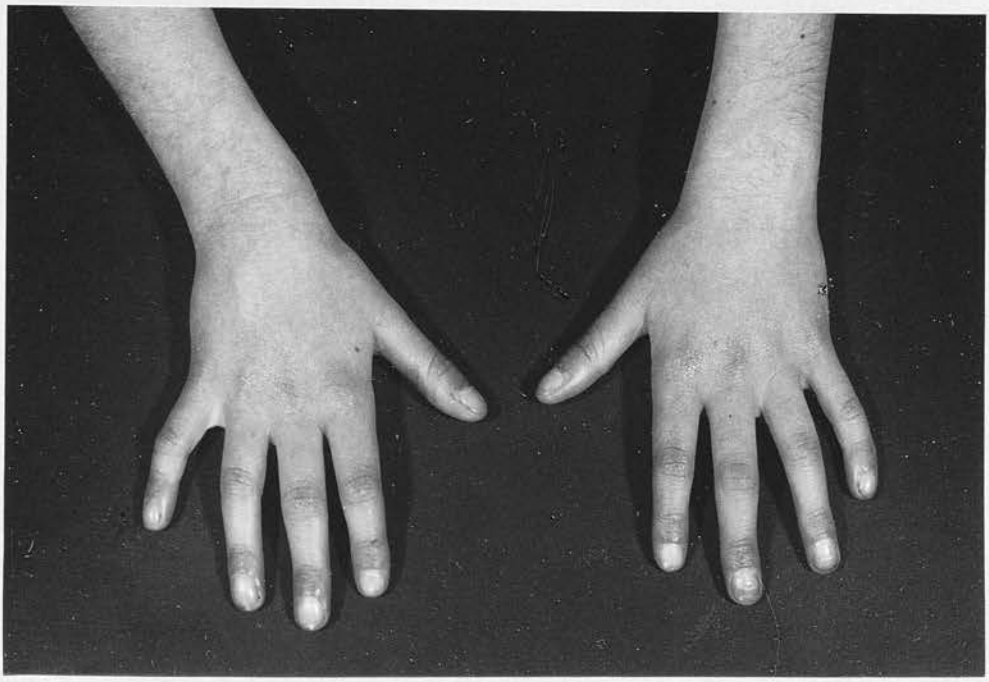


FIG. 74 Photograph of Case 39. Patent Ductus Arteriosus aged 7yrs. with Pulmonary Endarteritis, immediately after control of infection.
1) General appearance
2) Clubbing of fingers

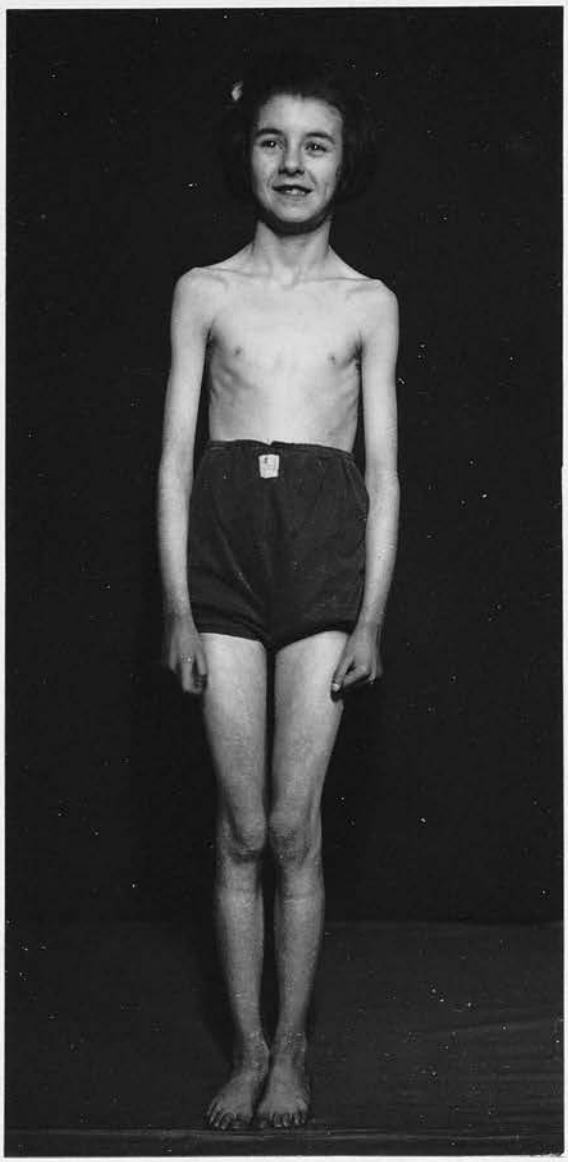


FIG. 75 Photograph of Case 39. Infected Patent Ductus Arteriosus with Pulmonary Aneurysm 1½yrs. after ligation.
No change in finger clubbing.

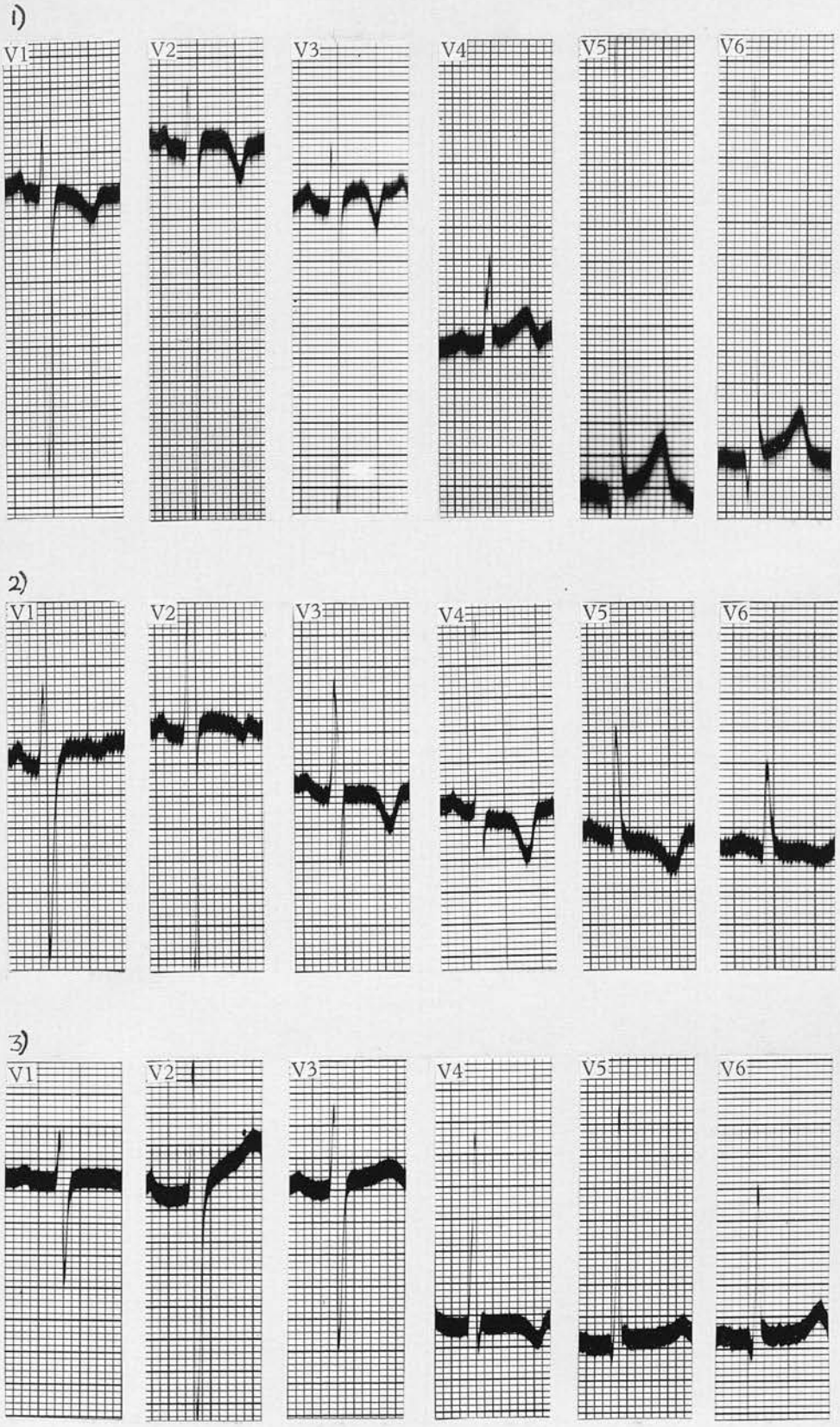


FIG. 76 Electrocardiogram of Case 39. Infected Patent Ductus with Pulmonary Aneurysm : Precordial Leads.

1) Before ligation. High Voltage(Deep S in V1, tall R in V5)
2) 1 month after ligation. Reduction in Voltage, ST depression, Steep T inversion V3 - V6
3) 2yrs. after ligation. Normal Electrocardiogram. Unusual T inversion V4

DISCUSSION

THE PROBLEM.

Earlier in this work, the problems in Patent Ductus Arteriosus still awaiting elucidation have been discussed briefly. During this investigation we have had chiefly in mind four:

Firstly, Problems of aetiology - the factor or factors preventing normal closure of the Ductus Arteriosus after birth;

Secondly, Further elucidation of the natural history of the disease, in particular the course it takes in the adult;

Thirdly, The Results, particularly long-term, of Surgery; and

Lastly, the Place of Surgery in this disease.

It is now proposed to discuss these problems more fully, in the light of the knowledge gained from the general study of the 110 cases, the operative results in the 70 cases submitted to operation, and the "follow-up" on the 64 survivors.

AETIOLOGY OF PATENT DUCTUS ARTERIOSUS.

From the nature of the defect, it is obvious that there are two critical periods in the development of the Ductus - (1) in the early embryonic phase when differentiation is taking place, i.e., between the fifth and eight week of intrauterine life, and (2) immediately after birth, when the Ductus normally closes (Araya and White, 1943). It is to these periods that we must look when seeking evidence regarding the causation of the condition.

We shall consider the immediate Post-natal Period first, since this is in some ways easier and more obvious. Physiologists have shown that within a few minutes of occlusion of the Umbilical Cord, the Ductus ceases to transmit blood (Barclay, Franklin and Pritchard, 1944), but that this Primary Closure produced by active muscular contraction of the wall of the Ductus is merely the first stage, and that later the muscle becomes replaced by fibrous tissue and obliteration becomes complete (Kennedy and Clark, 1941, 1942). These latter workers have also proved that a rich Oxygen supply either via the lungs or the Umbilical Vein is amongst the various stimuli promoting the Primary Closure, which appears to be independent of all nervous mechanisms. Kennedy(1942) himself believes that it is interruption of this stage which is responsible for most cases of Patent Ductus Arteriosus. If this is so, we must look for abnormal influences, operating at birth, which would interfere with the normal supply of Oxygen to the new-born babe. Of 93 cases where accurate Birth Histories were obtained, the delivery was such in 27 that this might well have occurred, although only ten babies were said to be definitely distressed at birth. As strong evidence, on the other hand, that Atelectasis and allied conditions play little part in the production of Patent Ductus is the fact that the average weight of the babies was 7½lbs., 25% weighing more than 9lbs., while only one child in the series was premature - a finding in agreement with other

observers (Araya and White, 1943). If deficient expansion of the lungs were the major cause of this condition, then prematurity would be almost certain to be found more commonly, whereas the incidence of prematurity in Patent Ductus is actually lower than in Congenital Heart Disease in general.

To turn now to Pre-natal causes of congenital defects, it has been shown that these may result from anomalies of either genes or environment, resulting in faulty differentiation and malformation. In the first, the defect is hereditary, in the second, it will not be transmitted to subsequent progeny (Warkany, 1947). In actual practice it is difficult to distinguish clearly between genetic and environmental causation of defect, since the finished product is always the result of the interaction of these two factors.

Evidence for Genetic Influence in the production of a defect may be found in

Familial concentration of a defect in sibships (though this may be a repetition of environmental effect),

High Incidence of congenital defects in relatives,

Sex Linkage,

Parental Consanguinity - the hallmark of the Recessive Gene.

In this study, there was a high incidence of congenital defects in siblings, parents and offspring of affected cases. In three families there was a pair of children suffering from Patent Ductus

Arteriosus and there were six other cases where close relatives suffered from other forms of Congenital Heart Disease. In eight others there was evidence of other congenital abnormality. This is a much higher proportion than would be expected in the population at random(Murphy, 1947, estimated approximately 47 individuals possessing congenital malformations to be born alive or dead in Philadelphia per 10,000 live births). The presence of additional abnormalities in the cases themselves is not necessarily evidence of genetic causation, since it has been shown that such multiple abnormalities may result from environmental factors as e.g. in the Rubella Syndrome.

The high incidence of females to males which is present in every series of Patent Ductus (8/3 in present series) is also strong evidence in favour of a genetic basis and against a purely mechanical one arising at birth.

There was no case of Parental Consanguinity in this series so that a rare recessive gene is unlikely to be the cause. Campbell, 1949, similarly found no such evidence in Congenital Heart Disease in general.

Amongst the Environmental factors which may result in similar congenital defects, "Phenocopies", emphasis has recently been placed on the rôle of infections during Pregnancy. Injection of 48-hour Chick embryos with Virus of Influenza A or Mumps has resulted in microcephaly. This is in harmony with

the clinical observations made by Swan, Tostevin, Moore, Mayo and Black, 1943, of congenital defects in infants following infectious disease during Pregnancy, particularly Rubella, the severity of the effects and the type, depending on the type of epidemic and the stage of foetal development when the disease occurs. Landtman (1948) has also stressed the rôle of maternal infections in the production of Congenital defects and has included Influenza as a cause.

Other known environmental factors which may affect the developing foetus are exposure to deep X-rays and dietary defects. In the animal severe Vitamin starvation has resulted in defects, e.g., Deficiency of Riboflavine in Cleft Palate, Vitamin A Deficiency in blindness, accessory ears, etc., but the degree of malnutrition of these animals has been far greater than is likely to occur in man. Murphy (1947) was unable to prove statistically that diet in man had any effect on the production of foetal malformation.

In this series, there is evidence in eight cases of maternal illness during pregnancy which might have adversely affected the developing foetus. In one case, German Measles in the first month of pregnancy resulted in a syndrome of Congenital Heart Disease and Deaf-Mutism, exactly comparable to the Rubella Syndrome described by Swan (1944). In another, there was a history of Mumps during pregnancy. In a third, the Mother had severe Influenza at the third month. These three cases each had a very large Patent Ductus. In four cases with severe

Hyperemesis and one of Jaundice, nutritional factors may have played a part. One Mother suffered from Hyperemesis in two pregnancies, both resulting in children with Patent Ductus Arteriosus, whereas two normal pregnancies resulted in two normal children. No case in this series was subjected to X-radiation during pregnancy.

The effect of interaction between genetic factors and environment has already been mentioned, e.g., the adverse effect of Maternal age. The proportion of defective children increases appreciably after the Mother has reached 30 years of age (Murphy, 1947). There is evidence in this series of the part played by Maternal Age in this disease, the average Maternal Age being 28.5 years. In 23 cases the Mother was over 30 years at the time of the birth.

There is thus fairly strong evidence that the occurrence of Patent Ductus is determined before birth. It may result either from Genetic or adverse environmental factors, e.g., Rubella, operating at the critical period of the fifth to eighth week of intra-uterine life. Recent work by Odé (1951) has shown after mid-term a thickening of the wall of the Ductus - the external diameter continuing to increase and the lumen remaining stationary. In the rat, the lumen actually decreases. This suggests that closure of the Ductus after birth is but the continuation of a process of obliteration begun about halfway through foetal life.

If this is so, it is possible that it is

interference with the obliterative process which is responsible for most cases of Patent Ductus, rather than failure of Primary Contraction as suggested by Kennedy (1942). Certainly, from observations of the Patent Ductus at operation, we have seen that in many cases the Patent Ductus is quite capable of contraction when stimulated. Since Prematurity does not play a part in the incidence of Patent Ductus Arteriosus, it is unlikely that lack of stimulus to contraction due to faulty oxygenation and poor expansion of the lungs plays a major rôle, though it may be a subsidiary factor. On the other hand, we have been able to study the Ductus in one case four months after ligation and found an obliterative endarteritis present, very comparable to that occurring normally in the infant. The known tendency for cases to recanalise after ligation suggests that this obliterative tendency is poor or absent in many of these cases.

THE NATURAL HISTORY OF PATENT DUCTUS ARTERIOSUS.

This series of 110 cases of Patent Ductus, having been unselected, has been taken as representing a fair cross-section of the various age groups, and has thus been used to build up a picture of Patent Ductus from infancy to old age.

It has once again confirmed the opinion of previous writers that the classical case is seen in the child of school age. In most such cases, the diagnosis is easy and may be based on auscultatory findings alone - a loud Gibson Murmur of Grade II or

III intensity, usually associated with a thrill, being present in 85% of cases at this age. The degree of incapacity varied considerably, from the boy of 13 in early congestive failure to the girl of 9 who could dance the Highland Fling. Few, however, were entirely symptom-free - only 12 in this entire series. The commonest symptoms proved to be tiredness, breathlessness, and recurrent coughs and colds (Nichol and Brannan, 1947 have offered an explanation of this latter complaint in early pressure by the Ductus on the left Bronchus). Statistical analysis of average height and weight, as a basis for estimating nutrition, showed that these children fell below normal as regards both. The average height and weight of Siblings were taken as "normal" figures. B.P. Studies confirmed a raised Pulse Pressure due chiefly to low diastolic Pressure, and a positive exercise test was obtained in 52 of 54 cases in which it was satisfactorily carried out. Approximately 70% had cardiac enlargement on X-ray at this stage; in 25% there was Left Ventricular Enlargement. Right Ventricular Enlargement was less frequently seen and on the whole, associated with less cardiac enlargement than was Left. Pulmonary Artery enlargement was constant, as were increased hilar shadows and pulmonary congestion, though hilar dance was rare - being seen in only six of 68 cases. Nine showed definite enlargement and 17 slight enlargement of the Left Atrium, and its presence was taken as corroborative evidence of a large shunt. Typical

increased pulsation on screen examination was seen in approximately 80% of cases. The X-ray appearances are thus very similar to those described by Donovan, Neuhauser and Sosman (1943), except that they did not demonstrate Right Ventricular enlargement in any cases and found Hilar Dance present in considerably more (1/3 against 1/10 in this series). Electrocardiographic findings are in agreement with those of Mannheimer (1950) and Wood (1950). Deep S in V1 and tall R in V5 were common though of doubtful significance in the schoolchild, being also found in the normal at this age. Six, with evidence of large shunt, showed signs of Left Ventricular Hypertrophy; none showed Right.

It is in the younger and the older groups - the infant and the adult - that the picture is less clear, and these have been of particular interest in this series. It is agreed that the auscultatory signs of Patent Ductus are, in most cases, absent at birth but present in almost 100% at 5 years. Observation of these younger cases at frequent intervals has demonstrated the development of the continuous murmur, and this in turn has shed light on some of the described atypical cases. In one case, the continuous murmur was present at 9 months, but in five others at first examination the murmur was systolic only, although with the reverberant character of the Gibson Murmur. Later a short diastolic murmur developed and finally the murmur became continuous with the establishment of the

normal pressure gradient between Aorta and Pulmonary Artery. This usually occurred between 2 and 5 years, although one case was 7 years of age before the classical murmur developed. Difficulty in diagnosis may thus arise in this age group, particularly at the stage of reverberant systolic murmur associated with accentuated and split second sound followed by a short diastolic murmur, i.e., before the murmur has become truly continuous. This may occur as a normal stage in the transition, but similar findings may be found in the case with associated high Pulmonary Pressure in which the murmur never becomes truly continuous, and in the severe case bordering on cardiac failure. Aids to the diagnosis at this time are increased Pulse Pressure, which is present early, combined with radiological features of generalised cardiac enlargement, Pulmonary Artery enlargement and congested lung fields (Screen examination is not helpful). High voltage may also be seen in the unipolar Electrocardiogram. Such findings are helpful, although none are specific for Patent Ductus.

It has already been mentioned that few cases are completely symptom-free. The majority of symptoms develop at the time of entrance to school, which proves a severe test for many of these cases. The tiredness and breathlessness on exertion which develop then may prove extremely incapacitating. Subsequently throughout school life there is little change in exercise tolerance or in clinical, radiological or electrocardiographic features.

Similarly in early adult life there is little change. Pregnancy is well tolerated in the third decade, one case having seven pregnancies without cardiac failure. Is there, therefore, justification for the view that this is a comparatively innocuous lesion and that the risks of Surgery far outweigh the natural risks?

Further investigation of the adult group of cases will answer this problem for us. We have seen that pregnancy is well tolerated in the third decade, but four cases out of five developed signs of cardiac failure either before or after delivery in the fourth and fifth decades. Similarly, of seven cases in this series observed above the age of 40yrs., no fewer than six have developed congestive failure, two associated with pregnancy. All the evidence suggests that deterioration in Patent Ductus is initially a very slow process. Since the myocardium is healthy and can stand up to the additional burden constantly imposed on it, the case of Patent Ductus may continue with few symptoms, but with increasing years the risk of Congestive Failure increases. When it does occur, it is sudden, severe, resistant to therapy (e.g., Cases 71, 75, 83), death frequently occurring within one to two years of the onset. An abnormal rhythm, usually Auricular Fibrillation, may be the precursor of congestive failure, and its relief by the judicious use of Quinidine, as in Case 79, may prevent the onset of failure, at least temporarily.

The other grave risk to these cases is the development of bacterial endarteritis. This has its

maximum incidence in early adult life. Seven cases occurred in this series between 16 and 32 years, which agrees with the maximum incidence between 16 and 25 years found by Hubbard, Emerson and Green in 1939. Childhood, however, is not devoid of risk, two cases in this series developing at 6 and 7 years respectively.

The above outline of the natural progress of the disease demonstrates clearly that Patent Ductus Arteriosus is by no means an innocuous lesion, but carries grave risks of infection at all times, and few cases above 40 years are free from serious symptoms of cardiac failure. Keys and Shapiro (1943) have estimated that the reduction in life expectancy is approximately 25 years. This would appear to be true of this series also. Analysis of the six severely affected cases over the age of 40 years showed that none had had symptoms in childhood or young adult life. Five had not been recognised till adult life. They may therefore fairly be taken to represent the end-stage of the relatively symptom-free case. Presumably, those with marked symptoms earlier do not reach this age at all. The low incidence of adult cases giving a history of recurrent respiratory infections such as is found frequently in the younger groups, is of itself suggestive that the prognosis of these cases with recurrent respiratory infections in childhood is bad.

This reduction in life expectancy is not, however, the whole reason why cases of Patent Ductus are so seldom seen in adult life in comparison with

the numbers seen in childhood. There is little to support a theory of spontaneous closure. Gilchrist (1945) has described one such case associated with regression of all signs. In two of Benn's cases (1947) the continuous murmur disappeared without disappearance of other signs. This does not appear to be common and did not occur in any of this present series, apart from certain conditions :-

The murmur was noticed to be atypical, though not unrecognisable, in association with Auricular Fibrillation (Case 79). The pitch was lower, and the site of maximum intensity under the third rib rather than the second space.

The murmur was noticed to be atypical in mild congestive failure associated with Auricular Fibrillation in Case 71. Presumably due to the increased Pulmonary Pressure, the murmur was systolic and diastolic, not continuous, the systolic murmur retaining the characteristics of the Gibson Murmur. With relief of the congestive failure, the Gibson Murmur returned but disappeared readily on exertion, and therefore could be easily missed on Out-patient Examination. Other signs, however, remained - Mitral diastolic murmur, high Pulse Pressure, Left Ventricular Hypertrophy - as an aid to diagnosis.

In Case 83, there was complete absence of the Ductus murmur during periods of severe cardiac failure in a girl of 23 years, who suffered in addition from Rheumatic Heart Disease (the only case in this

series).

With further rise in Pulmonary Pressure, Shunt Reversal may occur as in Case 75. The Gibson Murmur then disappears and is replaced by much less impressive systolic and diastolic murmurs, the picture in general being suggestive of Lutembacher's Syndrome, but with persistence of signs of Mitral Stenosis in failure and Left Ventricular Hypertrophy.

Unless it is appreciated that these atypical findings may occur, cases of Patent Ductus will be missed, and it is probable that this is so in many cases because of the fairly rapid development of cardiac failure masking the signs. One might wonder why such cases are not picked up at Autopsy. Gilchrist (1945) has already described the difficulties and in this series, the Stomal Ductus present in Case 75 and unsuspected during life, would easily have been overlooked had it not been looked for specifically because of the absence of other cardiac pathology.

RESULTS OF SURGERY.

Relief of symptoms was striking and immediate at all ages with the exception of cases where the operation was not completely successful. All were able to lead a normal life thereafter, including strenuous occupations such as Regular Army and Nursing, whereas before operation these would have proved too heavy. All were encouraged to take a pride in the achievement of physical fitness, and no fewer than three became Games Champions within a few

years.

Weight gains have been noticed by many observers (Gross 1940, Sellors 1945, Gross and Longino 1951), and have occurred in this series, but the impression was that the children still remained below standard. It has been proved statistically that there is increase in the actual growth rates, i.e., in the increase per annum, which is statistically significant, particularly as regards weight, but that the children even after some years still remain below standard.

In the successfully ligated case, complete disappearance of physical signs and reduction of Pulse Pressure to normal occurs immediately after operation, the systolic and diastolic pressures reaching a normal level about one month after operation. This result was the same in the end, regardless of age at operation or pulse pressure before operation.

Similarly, X-ray and Electrocardiographic changes showed reversibility. In 40 to 50% of cases the reduction in cardiac size was a true one. In others, the child grew and the heart to a less extent, so that the end result was the same. This reduction in cardiac size was slower in the adult group, though even in this group average cardiac area by one year after operation had decreased to upper limits of normal (+11%). Signs of Left Ventricular Hypertrophy in the Electrocardiogram, after initial increase associated with decrease in cardiac size, similarly

showed gradual reduction in signs and return to normality in all groups.

No Bacterial Endarteritis has developed in any case, following operation.

There is thus very definite evidence of the value of Surgery in these cases, particularly when one considers the uncertainty with which such patients must face the future in adult life. However, before one can assess correctly the place of surgery, one must consider the mortality and morbidity rates. Gross (1951) in his most recent publication has given his overall mortality rate as 2.1%, in asymptomatic cases less than 0.5%. In this series there were seven deaths, a mortality rate of 10%, but three occurred in gravely ill infected cases in pre-Penicillin days, who would not now be ligated without previous control of the infection by Penicillin. In non-infected cases the mortality rate was 4.9% (three cases, none of whom were symptom-free). The actual causes of death were similar to those of Gross - cardiac arrest (in one case of vagotonic type), post-operative collapse, haemorrhage at operation.

Post-operative complications were similar to those decribed by Jones, Dolley and Bullock, 1940, and Jones, 1947, the most common being Haemothorax and Atelectasis. Recurrent Laryngeal Paralysis occurred in four, presumably from involvement of the Nerve in post-operative fibrous tissue, since it was held free of the ligature in all cases. The most serious complications from the long-term point of view

were the Periductal Haematoma, which resulted in death at second operation, and Recanalisation, which occurred and persisted in five cases. The possibility of Recanalisation has proved a source of anxiety to many surgeons but has been rather less high in this series - 7% against 20% in Gross' series of ligated cases. Two of the five occurred before the value of ligating the Ductus close to the Aorta was appreciated. One was virtually inoperable, being Stomal. In one, recanalisation was minimal. Because of the risk of recanalisation, Shapiro and Johnson (1947) consider ligation obsolete. Gross (1951), though practising section in all cases, believes ligation is usually adequate in the child, but feels that section is essential over 20 years because of fixation and sclerosis of the Aorta.

THE PLACE OF SURGERY IN PATENT DUCTUS ARTERIOSUS.

With falling mortality rates and improved technique, most authorities are now agreed that all cases of Patent Ductus recognised in childhood should be submitted to Surgery in order to forestall later complications (Gilchrist and Mercer, 1947), since the risk is minimal at this age, post-operative complications fewer, and the changes reversible. (Although all adult cases in this series have shown return to normal after operation, irreversible cardiac disease in a man of 21 years submitted to ligation, has been described by Dry, Harrington and Edwards, 1948). The ideal age is probably 5 to 9 years, since this allows time for weight to be made up and ligation

at this time permits normal development at school.

The problem of the adult case is more difficult since the risk is considerably greater (two cases dying from Cardiac Arrest at operation were in this group), and technically the operation is more difficult, probably requiring section of the Ductus in all cases because of the approximation of the Pulmonary Artery to the Aorta in adult life and the difficulty of mobilising the latter because of sclerotic changes such as are frequently present. From our experience of the rapid rate of deterioration, once begun, any such signs developing in the young adult, e.g., increasing cardiac enlargement or early signs of congestive failure, should be taken as indicating operation, since the outlook is poor.

The cure of Bacterial Endarteritis in the days before Penicillin by simple ligation was a great advance (Touroff and Vesell 1940, Touroff, Vesell and Chasnoff 1942, Touroff 1942, 1943), and three cases in this series were thus completely cured without the use of Antibiotics. Our experience on the whole, however, of ligation in the infected Ductus has been less happy than in the non-infected cases, which itself is a strong indication for early operation in the non-infected case. This and the advent of Penicillin therapy raises the problem of whether to await control of the infection by Penicillin before undertaking ligation. On the whole, our cases have done better with pre-operative control of the infection with Penicillin, and two of three cases who

died following ligation without Penicillin, did so because of the gravity of their illness rather than as a result of operation. The two cases who survived operation after Penicillin therapy were both too ill at the outset for operation to be considered. Penicillin thus has an important part to play in the preparation of the seriously ill case for operation.

With increasing numbers of cases being submitted to Surgery, accurate diagnosis is essential. In most of the young cases, there is little difficulty with typical murmur and corroborative evidence. In the youngest cases there may be some difficulty, but usually in such cases there is no urgency and time will make the diagnosis clear. In a young child, developing congestive failure, the presence of a systolic murmur at the Pulmonary Area with the quality of the Gibson Murmur, together with an accentuated second sound and a softer diastolic murmur, should suggest the presence of a Patent Ductus. Such cases with raised Pulmonary Pressure have been described by Cournand (1949), Wood (1950), with confirmation by Catheterisation, angiocardiography and operation.

The presence of an abnormally slow pulse may make the diagnosis difficult, as the diastolic component then becomes more obvious and the murmur may appear discontinuous, as e.g. Cases 29, 93. In the case with a small Ductus, during rest the murmur may be systolic only, as in Case 91, but quickly becomes continuous with exertion or excitement, in contradistinction to the large Ductus, where exertion

may make the continuous murmur disappear.

In the older case, the Ductus murmur may be atypical or absent in congestive failure or Shunt Reversal. This has already been discussed, and the diagnosis should be considered in all cases of congestive failure with signs of Mitral Stenosis and Left Ventricular Hypertrophy without Aortic Regurgitation, or in cases simulating Lutembacher's Disease, but with Left Ventricular Hypertrophy. The presence of an arc of calcification low in the Arch of the Aorta, smaller than that occurring in the ordinary sclerotic Aorta, has been stressed as occurring in the older case of Patent Ductus Arteriosus (Lenègre, Kilaidonis and de Boux, 1948, Ruskin and Samuel, 1950). The Arch of the Aorta should be carefully scrutinised in all doubtful cases for this valuable piece of corroborative evidence. It was present in five of the cases above 40 years in this series.

Other causes of continuous murmur may also confuse, as e.g., Venous Hum, but this disappears on laying the patient flat whereas the Ductus Murmur is accentuated in this position. Aortic Septal Defect may produce a continuous murmur, but the signs are typically extremely coarse and situated lower than the Gibson Murmur. A high Ventricular Septal Defect with Aortic Regurgitation may produce systolic and diastolic murmurs very like Patent Ductus Arteriosus, but these are never truly continuous. The character of the systolic component is different from that of

the Ductus, but nevertheless such a murmur may be difficult to differentiate from an atypical Gibson Murmur associated with Pulmonary Hypertension.

SUMMARY.

A clinical study of 110 cases of Patent Ductus Arteriosus has been made with a view to elucidating further the Aetiology of the condition, the Natural History of the Disease and the place of Surgery in its treatment.

Aetiological Factors have been discussed as

1) Prenatal Influences - Genetic and Environmental causes of such malformation.
2) Natal and Post-natal Influences.

The Natural History of the Disease has been studied under the following headings :-

1) Symptoms.
2) Nutrition.
3) Auscultatory and Blood Pressure Studies.
4) Radiological Features.
5) Electrocardiography.

Seventy cases were submitted to operation and studies made at operation with special reference to size and appearance of the Ductus, changes in Pulse Rate and in Blood Pressure before and after ligation.

Sixty-four cases surviving operation have been followed for periods of six months to nine years with a view to establishing the place of Surgery in this disease. A similar method of study was employed as before operation.

The Infected Ductus has been considered separately.

A Summary of the Case Notes of the 110 cases is given in the Appendix. Eight cases of special interest have been described separately, with Illustrations.

Aetiology.

The relative merits of Prenatal and Natal Influences have been discussed. Evidence has been submitted in favour of Prenatal Determination of Patent Ductus (a) genetic or (b) environmental (infective), the defect being probably a failure of the obliterative process rather than a defect of Primary Closure.

The Natural History of Patent Ductus Arteriosus.

The natural course of the disease has been outlined by study in age groups (a) Pre-School Child; (b) School Child; (c) Adult. The risks of the development of Bacterial Endarteritis and Congestive Heart Failure have been discussed and the insecurity of the future for those over 45 years stressed.

Surgery in Patent Ductus Arteriosus.

The operative Morbidity and Mortality and the Results of Surgery have been reviewed. The place of Surgery has been assessed in the light of the knowledge gained of the Natural History of the disease.

Ligation of Patent Ductus is recommended in all cases recognised in childhood, the optimum time being between 4 and 8 years when post-operative

complications are lowest.

The place of Surgery in the Adult case has been discussed. It is considered that all infected cases and probably all adults showing deterioration in exercise tolerance or rapid increase in heart size should be submitted to operation, since deterioration once begun is rapid.

Finally, some of the difficulties in accurate diagnosis have been discussed.

A P P E N D I X.

1). Summary of Case Notes of 110 Cases of Patent Ductus Arteriosus.

2). Bibliography.

SERIES OF 110 CASES OF PATENT DUCTUS ARTERIOSUS

SUMMARY OF CASE NOTES

Cases are numbered thus -

1 to 70 in order of ligation
71 to 110 in chronological order according to year of birth

Abbreviations used in Summary :

B.P. Blood Pressure
C.H.D. Congenital Heart Disease
C.T.R. Cardiothoracic Ratio
E.C.G. Electrocardiogram
H.S. Heart sounds
L.A. Left Atrium
P.A. Pulmonary Artery
P.2. Second heart sound at Pulmonary area
Size of heart (± %) - figure refers to cardiac area expressed as % of normal (Meyer method).
Gibson Murmur - this has been used as suggested by Gilchrist (1945) to describe the classical continuous murmur of Patent Ductus Arteriosus. The number I, II, III or IV following refers to intensity of the Murmur.

1. J.D., male, aged 19.

Admitted 30.8.40, with Subacute Bacterial Endocarditis of three months' duration. C.H.D. recognised at age 2yrs.
Examination showed loud Gibson Murmur (III), infarcts both lungs, blood culture grew Strept. Viridans on several occasions. B.P. 110/42 - 105/50.
No improvement following course of Sulphapyridine and Sulphathiazole.
Operation 12.10.40 - large, thin-walled Ductus found with old, inflammatory reaction around.
Died three days after operation from massive collapse of lung.

2. T.B., male, aged 18.

Admitted Oct., 1940, increasing tiredness and breathlessness on exertion for nine months. C.H.D. recognised at age 5.
Examination - loud Gibson Murmur (III) and thrill. No Mitral Murmurs. Capillary pulsation. B.P.170/64.
Operation 23.1.41, aged 18, Ductus approximately 15mm. wide and 5mm. long, occluded by braided silk. B.P. after operation 150/110.
Post-operative course - Haemothorax, and residual pleural thickening. Recanalisation of Ductus on 12th day. Ductus murmur persisted for 10 months but had disappeared two years later.

Last seen nine years after operation. H.S. perfect. B.P. 120/74. Pleural thickening with calcification persists on left side. Considers himself in perfect health.

3. B.S., male, aged 21.

"Fainting attacks" 18 months. Fatigue two years. Examination - loud Gibson Murmur (II) B.P.130/52. Heart slightly enlarged. P-R interval 0.28sec.
Operation 28.8.41, aged 21, Ductus 15mm. long and 7.5mm. broad. Ductus firmly clasped by silver ring without complete obliteration. B.P. after operation 134/88.
Post-operative course - Haemothorax - aspirated. Inconstant Gibson Murmur which gradually lessened.
Last seen 3½ years after operation. No Gibson Murmur. B.P. 124/74. Heart size measured on X-ray smaller. Considers himself improved by operation.

4. D.S., male, aged 13.

Always easily tired, "blue turns" on excitement for nine years, increasing breathlessness one year, swelling of ankles one month.
Examination - poorly nourished boy (height 5ft. 2ins., weight 80lbs.), coarse Gibson Murmur (II) and thrill, P2+. No Mitral diastolic Murmur. B.P. 102/45. Moderate cardiac enlargement (+22%).
Operation 26.7.42 aged 13 years - Ductus ligated in two places with extra strong double silk.
Post-operative progress - Haemothorax (aspirated). No post-operative murmurs. B.P.98/74. Gained 8ins. and 3 stones in two years following operation.
Last seen 1951, 8½ years after ligation. Has been in Regular Army for four years, is Trainer of Regiment Football Team, Boxing Champion (Welter-weight) for Division, plays water-polo, and is a cross-country runner. Height 5ft. 11ins., weight 146lbs. Heart sounds perfect. B.P. 124/80. Heart size normal (-6%). E.C.G. high voltage, otherwise normal.

5. G.B., male, aged 13.

Easily tired, breathless on exertion all his life. C.H.D. recognised at 5yrs.
Examination - moderately well nourished but small. Humming-top murmur (II) heard widely. No Mitral murmurs. P2+. B.P.110/50. Generalised cardiac enlargement (+40%).
Operation 4.12.43, aged 13yrs. - large Ductus ligated in two places with double silk ligatures.
Post-operative progress - H.S. normal for two days, B.P. 120/86. Recanalisation on third day when systolic murmur heard followed by continuous murmur on tenth day and thrill on 17th day. B.P.100/50.

Last seen 1947, four years after ligation. Unable to hold heavy job. Remains small - aged 17 years, height 4ft. 10ins., weight 81 lbs. Gibson Murmur (II) remains, P2+. B.P. 105/50. Cardiac enlargement (+38%). No unipolar E.C.G.

6. B.R., female, aged 5.

Unduly sensitive to cold, tired at end of day. C.H.D. recognised aged 5.
Examination - average nutrition. Very coarse Gibson Murmur (III) and thrill. B.P. 84/46. Heart size within normal limits.
Operation 3.2.44 aged 5yrs. Ligation difficult owing to large Pulmonary Artery and horizontal course of Ductus under the arch of the Aorta. Ductus tied with single ligature of umbilical tape.
Post-operative progress - Haemothorax (aspirated). H.S. normal for six days. B.P. 108/80, but thereafter humming-top murmur recurred.
Last seen 1949, 5½ years after operation - getting fitter as she gets older, able for gym, etc. Gibson Murmur (II) and thrill persist but less intense than formerly. B.P. 95/55 with fall in diastolic to 25 following exercise. Heart size remains within normal limits (+8%) - Pulmonary Artery is enlarged, and there is still a little increased pulsation in great vessels. Unipolar E.C.G. normal.

7. B.F., female, aged 5.

Easily tired and breathless since going to school. C.H.D. recognised aged 5yrs.
Examination - Gibson Murmur (III) with well-marked systolic component. Faint thrill. P2+. B.P. 98/50. Heart size within normal limits (-4%). Observed for two years - definite increase in intensity in signs, thrill became continuous.
Operation 22.2.44, aged 7yrs. - Ductus longer than average and 5mm. wide. Occluded by two silk ligatures, silver clip and cellophane.
Post-operative progress - No post-operative murmurs, H.S. perfect, B.P. 100/74.
Last seen 1949, five years after operation - has done better at school since operation - growing well. Heart sounds perfect, B.P.96/76, heart size well within normal limits. Unipolar E.C.G. normal.

8. J.J., male, aged 18.

Working as shipwright, excessively tired at end of day. Played Rugby up to one year before, but had to give it up because of fatigue and breathlessness at times.
Examination - good nutrition and development. Loud Ductus murmur (II) P2+. No Mitral murmurs, B.P. 130/70. Heart size, T.D. within normal limits, but cardiac area +23%.

Operation 26.2.44, aged 18yrs. - Ductus 5mm. long and 10mm. broad, occluded by two silk ligatures, silver clips and cellophane.
Post-operative progress - extensive collapse and haemorrhagic effusion at left base (aspirated). Heart sounds remained perfect after operation, B.P. 112/80.
Last seen 1950, 6½ years after operation - very fit and playing Rugby regularly. Heart sounds perfect, B.P. 120/84. Heart size normal and has decreased considerably compared with pre-operative X-ray (+4%). Unipolar E.C.G. normal.

9. G.B., male, aged 6.

Easily tired and slightly breathless on exertion since going to school.
Examination - below average height, nutrition good. Gibson Murmur (III) and thrill. B.P. 100/48. X-ray heart enlarged (+20%). L.V. prominent.
Operation 25.3.44, aged 6yrs. - Ductus very short, ligated with two braided silk ligatures, silk clips and cellophane.
Post-operative progress - no effusion. H.S. perfect. B.P. 105/75.
Last seen 1950, six years after ligation. Perfect health (still below average height and weight). Playing Football. H.S. perfect, B.P. 115/70. X-ray - heart size remains above normal (+20%), but stocky build. E.C.G. normal limits.

10. A.L., female, aged 5.

Breathless on exertion, blue around lips when running 2-3yrs. Thinner and smaller than rest of family.
Examination - below standard height and weight. Loud Gibson Murmur (II) and thrill. B.P.120/55. Heart enlarged (+30%), displaced to left and rather mitral in shape. Two years' observation, no change.
Operation 22.4.44, aged 7yrs. - long narrow Ductus, ligated by double silk ligatures, silver clips and cellophane.
Post-operative progress - no effusion, but atelectasis of left lower lobe. No cardiac murmurs. B.P.108/75.
Last seen 1949, five years after operation. Still below standard height and weight. H.S. normal, B.P. 110/75. Heart size normal (+8%), lung fields normal. E.C.G. high voltage unipolar leads, otherwise normal.

11. J.A., female, aged 5.

Breathless and tired following exertion.
Examination - up to standard height and weight. Gibson Murmur (II) and thrill. B.P.110/50.
Operation 25.4.44, aged 8yrs. - short, wide Ductus, tied with two double silk ligatures, silver clips.
Post-operative progress - small effusion (not aspirated). H.S. normal, B.P.120/88.

Last seen 1950, six years after operation. Very fit, well above average height and weight. Doing well at school sports. H.S. perfect, B.P. 110/75. X-ray - heart size normal (-4%), P.A. still prominent. E.C.G. normal limits.

12. M.B., female, aged 28.

Admitted with S.B.E. of six months' duration. Always a little breathless. C.H.D. recognised at age 8. Six attacks of Pneumonia during last six months (Staphylococcus Aureus cultured from sputum) - fifth attack treated by Penicillin (100,000 units daily by intramuscular route). Improved - two weeks later relapsed and failed to respond to Penicillin a second time.

Examination - Gravely ill, café-au-lait complexion, congestive heart failure with oedema of legs, sacrum and lumbar region. Coarse thrill and loud Gibson Murmur (II) - Corrigan pulse, capillary pulsation, B.P.180/46. Patchy consolidation of both lungs. Hb.50%. Urine contained R.B.Cs. Blood Culture sterile, spleen palpable. X-ray heart - serial X-rays over six months showed progressive increase in size with enormous dilation of P.A., multiple lung infarcts. Congestive failure cleared with Digitalis and Neptal.

Operation 30.5.44, aged 29yrs. - very large Ductus (10mm. long, 15 to 20mm. broad). Ligated in two places with double silk.

Post-operative course - no cardiac murmurs, B.P.115/94. No return of congestive failure. Three days after operation, suddenly became breathless, collapsed and died after half an hour.

Post-Mortem - large amount clotted blood left pleural sac. Both lungs showed infarction - with healing and healed infarcts.
Heart - both Ventricles were hypertrophied.
Pulmonary Artery was grossly enlarged, circumference 8.75cm. above Pulmonary Valve, compared with Aorta 7.2cm. Mass of vegetations in P.A., extending down to Pulmonary valve and up to bifurcation. Most profuse opposite mouth of Ductus. Well-marked atheroma at the root of the Ascending Aorta and a smaller patch first distal to the aortic orifice of the Ductus.
No vegetations were found in the Ductus itself.

13. A.P., female, aged 11.

C.H.D. recognised aged 4yrs. Has to rest after school. No gyms, etc.

Examination - below standard height and weight. Well marked signs of P.D.A. B.P.105/50. Heart size within normal limits (+5%) - increased pulsation. E.C.G. normal limits. No unipolar leads.

Operation 28.11.44, aged 11yrs. - moderate sized Ductus ligated with two silk ligatures.

Post-operative course - small effusion resolved without aspiration. H.S. normal, B.P. 128/86.
Last seen 1950, six years after operation. Plays hockey, tennis, swimming. Well apart from Renal colic due to Calculus. Still below average height and weight (5ft. 2ins., 6st. 8lbs.), H.S. perfect. X-ray heart - normal apart from slight prominence of Pulmonary Artery; size -15% of predicted normal. E.C.G. normal limits.

14. M.S., female, aged 6.

Admitted with S.B.E. of six months' duration. Loss of weight and increased pallor 13 months, no energy six months. C.H.D. recognised aged 14 months.
Examination - febrile - below standard nutrition. Loud Gibson Murmur (III) and thrill. B.P.100/44. Multiple lung infarcts. Spleen palpable. Blood Culture Streptococcus Viridans (two occasions) Hb.54%. Heart enlarged on X-ray with increased pulsation. E.C.G. normal limits.
Operation 2.12.44, aged 6yrs. Ductus ligated without difficulty (two silk ligatures).
Post-operative course - no effusion, small embolus right lung on third day. No cardiac murmurs, B.P.110/70.
Last seen 1948, four years after operation. Very well. Height and weight still below average. Perfect heart sounds, B.P.115/70. X-ray heart - size at upper limit of normal. E.C.G. within normal limits.

15. E.G., female, aged 5.

Well up to going to school. Thereafter unduly easily tired. Not thriving.
Examination - well below standard height and weight (partly familial). Well-marked Gibson Murmur (II) and thrill. B.P. 85/40. X-ray heart size within normal limits (-4%). Shape not typical. Two years observation. Never well. Greater enlargement of right side than usual. Typical increased pulsation.
Operation 22.2.45, aged 7yrs. Average sized Ductus ligated with two silk ligatures.
Post-operative course - small haemothorax. No cardiac murmurs, B.P. 90/55.
Last seen 1951, six years after operation - much more energy - a real "Tomboy". Tired recently, but doing all family washing (aged 12 years). Still small for age. Heart sounds perfect. P2 normal, B.P. 120/74. X-ray of heart well within normal limits regarding size (-12%). Unipolar E.C.G. normal, apart from high voltage.

16. J.P., female, aged 10.

C.H.D. recognised at school (age 4½ years). No complaints.

Examination - well developed girl above standard height and weight. Gibson Murmur (II) and thrill. B.P. 138/66, after exercise 180/0. General enlargement of heart (+28%) with increased pulsation. E.C.G. normal.
Operation 5.3.45, aged 10yrs. Broad, rather short Ductus (5mm. long, 10mm. wide). Periductal inflammation and fibrosis noted. Ligated with two silk ligatures.
Post-operative course - Septicaemia, broncho-pneumonia, extremely ill for two months, no response to Sulphathiazole or Penicillin. Organism not isolated. Finally good recovery. No cardiac murmurs. B.P. 120/75.
Last seen 1951, six years after operation. Well developed girl, even more fit than before operation. Heart sounds perfect, B.P. 125/80. Heart size now upper limit of normal (+8%). Slight prominence of P.A. remains. Unipolar E.C.G. normal.

17. M.S., female, aged 11.

C.H.D. recognised at 10 months when she had Whooping Cough. No disability noted.
Examination - loud, roaring Ductus murmur (III), B.P. 110/46. Heart size increased (+40%). L.A. enlarged. Typical pulsation on X-ray.
Operation 13.10.45, aged 11yrs. - short, wide Ductus. Ligated with two silk ligatures.
Post-operative course - haemorrhagic effusion (aspirated). Systolic murmur persisted and localised diastolic which disappeared after exercise. B.P. 96/72. Keloid scar.
Last seen 1951, 5½ years after operation. Very fit. Realises now she was previously handicapped. Soft systolic murmur persists at left border of Sternum which disappears on deep inspiration (regarded as non-organic). No diastolic murmur. B.P.115/68. X-ray slight broadening of supracardiac shadow, otherwise normal. Cardiac area +5%. Unipolar E.C.G. normal apart from slightly increased voltage.

18. N.B., female, aged 5.

Breathless, easily tired, not growing for one year.
Examination - well below standard height and weight. Tinge cyanosis. Capillary pulsation. Gibson Murmur (III). B.P.125/60, after exercise 104/10. X-ray - heart enlarged (+30%) - typical.
Operation 15.12.45, aged 5yrs. Large Ductus, ligated with two silk ligatures.
Post-operative course - slight strider following operation. No cardiac murmurs. B.P. 150/106. Sudden death 23hrs. after ligation. No autopsy.

19. R.C., male, aged 14.

Breathless on exertion - unfit for games. Small for his age.

Examination - well below average height (-18cm.) and below average weight (-11kgm.). Gibson Murmur (II) B.P. 120/70. X-ray atypical, right side more prominent than left - size within normal limits (+5%). E.C.G. high voltage, IVF shows ST depression with diphasic T wave.
Operation 16.3.46, aged 14yrs. - Ductus 10mm. broad, less in length. Tied with two silk ligatures.
Post-operative course - uneventful. No cardiac murmurs. B.P, 130/90.
Last seen 1950, four years after operation. Very fit, very energetic, cycles 100 miles every Sunday, swims and golfs. Perfect heart sounds. B.P.125/75. X-ray shows slight prominence of supracardiac shadow to left of midline - shadow appears to be vascular, probably connected with operation. Otherwise normal. Unipolar E.C.G. high voltage.

20. A.I., female, aged 16.

Admitted with S.B.E. of one week's duration. Shivering, loss of appetite, sweating, seven days before admission.
Examination - swinging temperature. Well-marked Gibson Murmur (II) and thrill. Corrigan pulse and capillary pulsation. B.P. 140/50. Spleen palpable. Urine no R.B.Cs. Blood Culture - Streptococcus Viridans. X-ray typical. Cardiac area +19%.
Operation 2.5.46, aged 16yrs. Ductus very broad and short with enlarged Pulmonary Artery overlying. Ligated with two silk ligatures.
Post-operative course - haemorrhagic effusion (aspirated). No cardiac murmurs. B.P.116/80. Slightly keloid scar.
Last seen 1950, four years after operation. Very well, engaged to be married. More fit than before ligation. Well developed girl. Heart sounds perfect. B.P. 125/84. Size and shape of heart on X-ray within normal limits (+4%). Unipolar E.C.G. normal.

21. M.F., female, aged 27.

Admitted with S.B.E. of nine months' duration. Tiredness and exhaustion since extraction of teeth nine months before. Losing weight for three months (diagnosed as Phthisis). Had always been easily tired, never went to school but had married and had three babies without difficulty.
Examination - on admission gravely ill, swinging temperature. Gibson Murmur (II) and thrill, localised to II left intercostal space. Corrigan pulse. B.P.105/50. Spleen palpable two finger breadths below costal margin. Blood culture - five consecutive cultures grew Strept. Viridans.

Considered to be too ill for immediate surgery. Course of Penicillin given, 0.5 million units daily

for 31 days. Following start of therapy, she developed a series of embolic incidents - petechial spot on Left Conjunctiva, pulmonary infarcts on two occasions, R.B.C. in urine, red blood in stool. No further infarcts after 15th day. Blood culture negative after start of Penicillin.
Operation 15.10.46, aged 27yrs., 26 days after start of Penicillin. Large Ductus found, 20mm. diameter, less in length. Ligated with two silk ligatures.
Post-operative course - Penicillin continued for five days. Rapidly recovered. Small haemorrhagic effusion aspirated. No further infarcts. Very localised pulmonary diastolic murmur persisted. B.P.110/80.
Last seen 1950, four years after operation. Had kept well. Able for housework and looking after children. Shortly before last seen had had attack of Pneumonia. No recurrence of S.B.E. Still much underweight. During four years since operation, murmur has become more marked and now has loud Gibson Murmur (II) with systolic intensification under clavicle and down left border of Sternum, and associated with it a thrill. B.P.105/70 with no fall in diastolic after exercise. X-ray shows opacity around Pulmonary Artery and slight unfolding of Aorta. Brisk pulsation over Left Ventricle and Pulmonary Artery on screen examination. Cardiac area remains increased (+30%). Unipolar E.C.G. still unusual, with high voltage in precordial leads and deep Q waves (5mm.) V4, V5, V6.

22. C.G., female, aged 5.

Easily tired, but otherwise well. Slightly blue after coughing.
Examination - well developed, above average size. Systolic murmur at Pulmonary area with accentuated second sound (?Ductus). B.P.108/68. X-ray heart consistent with P.D.A. Increased pulsation on screen examination. Aged 6yrs., no change. Aged 7yrs., developed continuous murmur (II). B.P.110/64. X-ray showed no material change in size during five years of observation (age 5 C.T.R. 51.2, age 10 C.T.R. 50.4) - No unipolar E.C.G.
Operation 13.3.47, aged 10yrs. Large Thymus. Large Ductus (15mm. broad) but very short. Ligated with two silk ligatures.
Post-operative course - uneventful. No cardiac murmurs, B.P.115/80.
Last seen 1950, three years after operation - growing well. Swims and cycles. H.S. perfect, B.P.115/68. X-ray heart within normal limits apart from slight prominence of P.A. Unipolar E.C.G. slight ST depression V5, V6, otherwise normal.

23. M.W., female, aged 4.

Noticed to be more breathless than her brothers and sisters.

Examination - typical Gibson Murmur (II), B.P.110/50 with fall in diastolic following exercise. X-ray heart unusual, appearance suggesting enlargement of Right Ventricle. Slight generalised enlargement (+18%). No increase in four years of observation. E.C.G. no unipolar leads.
Operation 3.6.47, aged 8yrs. Ductus of moderate size, ligated by two silk ligatures.
Post-operative course - uneventful. No cardiac murmurs. Diastolic pressure did not rise until 48 hours after operation. Thereafter B.P.115/70.
Last seen 1951, four years after operation. Very fit. Above standard height and weight. Skin around wound remains hyperaesthetic. H.S. perfect. B.P. 120/72. X-ray heart remains globular but size and shape within normal limits. Unipolar E.C.G. high voltage, otherwise normal.

24. E.C., female, aged 12.

Increasing breathlessness and tiredness. Recurrent bronchitis since 3 years of age.
Examination - tall but underweight for her age. Gibson Murmur (II), with slight thrill. B.P.110/62, X-ray heart, size within normal limits (-8%). Prominent P.A. Pulsation typical.
Operation 24.6.47, aged 12yrs. Large Ductus 10mm. in breadth, less in length - ligated with two silk ligatures.
Post-operative course - developed massive haemothorax and Staphylococcal Empyema, necessitating rib resection. Developed keloid scar, which finally required excision.
Last seen 1950, three years after operation. Never breathless or tired. Much better than pre-operative. Working in factory. H.S. perfect, B.P.115/70. X-ray shows less pulmonary congestion than before operation. Heart size within normal limits. Unipolar E.C.G. normal.

25. M.E., female, aged 26.

Admitted with S.B.E. of two weeks' duration. Fever and sweating for two weeks. Previously always short of breath on hills.
Examination - pale and thin, becoming wasted. Swinging temperature. Well-marked signs, with Gibson Murmur (III) and thrill. B.P.120/65. X-ray - slight cardiac enlargement (+19%) - with prominent P.A. Pulmonary Vascular markings increased but no infarcts. Blood Culture on six occasions grew Streptococcus Viridans. No peripheral emboli.
Operation 8.7.47, aged 26yrs. Large Ductus - occluded by two silk ligatures. No positive blood culture following ligation.
Post-operative course - rapid recovery - haemorrhagic effusion requiring repeated aspiration. No cardiac murmurs. B.P. 120/75.

Last seen 1947, five months after ligation. Very well. No cardiac murmurs. B.P.120/90. X-ray shows pulmonary vascular markings less than before, Heart displaced to left.
Married 1948 - one year after operation. Has not reported since.

26. M.T., female, aged 7.

Referred by School Medical Service. No complaints. Never breathless or tired.
Examination - of average nutrition. Well-marked signs with Gibson Murmur (III) and thrill. B.P. 110/65. X-ray showed slight generalised cardiac enlargement (+12%). No change during year before ligation.
Operation 10.7.47, aged 8yrs. Moderate Ductus 10mm. wide tied with two silk ligatures.
Post-operative progress - uneventful. No cardiac murmurs. B.P.110/78. Developed keloid scar.
Last seen 1951, four years after operation. Very robust, well above standard height and weight. Does tap-dancing. Has gained advanced certificate for swimming. Scar remains keloid. Perfect heart sounds, B.P.120/84. X-ray - heart size remains increased (+15%) - hilar markings prominent. L.A. still a little enlarged. Unipolar E.C.G. high voltage. Otherwise normal.

27. G.S., male, aged 5.

Referred by School Medical Service - no complaints.
Examination - nutrition sub-normal, bounding neck vessels. Well-marked Gibson Murmur (II) and thrill. B.P.98/44. X-ray generalised enlargement (+20%). Prominent P.A. Slight enlargement Left Atrium.
Operation 5.8.47, aged 5yrs. Ductus 10mm. broad, tied with two silk ligatures.
Post-operative progress - small effusion which resolved without aspiration. No cardiac murmurs. B.P.110/86.
Last seen 1950, three years after operation - has grown 8ins., and gained 17lbs. Very fit. Perfect heart sounds. B.P.115/80. X-ray - cardiac area reduced (+15%). Lung vascular markings less - L.A. not enlarged. Unipolar E.C.G. - deep S in V1, tall R V5, otherwise normal.

28. C.M., female, aged 5.

Fainting attacks with slight injuries, otherwise well.
Examination - well developed, above standard height and weight. Gibson Murmur (III) and thrill. B.P.120/73. X-ray - heart size within normal limits (+6%). Prominent Pulmonary Artery. Typical increased pulsation over L.V. and P.A. No change during two years' observation.
Operation 23.9.47, aged 7yrs. Large Ductus, tied with two silk ligatures.

Post-operative progress - Haematuria three days after operation. Haemorrhagic pleural effusion requiring aspiration. No cardiac murmurs. B.P.115/78.
Last seen 1950, three years after operation. Full of energy. Doing well at school. Has gained swimming certificate. Heart sounds perfect. B.P.120/80. X-ray slight bulge L. cardiac border at level of fourth rib - otherwise normal size and shape (+2%). Unipolar E.C.G. high voltage left precordial leads, otherwise normal.

29. R. McN., male, aged 21.

Working as miner for six years, breathlessness on exertion two years, becomes flushed and dizzy when stooping.
Examination - stockily built - height 5ft. 4ins. Bounding neck vessels, slow pulse, continuous murmur (II) at Pulmonary area with accentuated and split second sound. At times in upright position murmur appears discontinuous. B.P. 124/62. Exercise test positive. No change in B.P. when stooping. X-ray - heart within normal limits regarding size - Mitral shape with prominent P.A., typical increased pulsation.
Operation 30.9.47, aged 21yrs. Ductus 10mm. broad, ligated with two silk ligatures.
Post-operative progress - Haemothorax requiring aspiration. No cardiac murmurs. Diastolic pressure rose after ligation to 80mm., but fell on seventh day to 60, thereafter remained low: no murmur heard. Exercise test remained positive.
Last seen 1950, three years after operation. Has taken up Nursing as Career. Can cycle 75 miles a day. Perfect H.S. B.P.120/60, Exercise test negative. X-ray heart little change since before operation, but now has no increased pulsation. Unipolar E.C.G. normal.

30. J.D., male, aged 32.

Admitted with four months' history of bacterial endarteritis - cough, tiredness, pallor for three to four months. High fever two months. No embolic episodes. No history of teeth extraction. Had been champion of school games, but was unfit for work with Forestry Commission, age 25 years.
Examination - café-au-lait complexion with pigmentation over forehead. Tinge cyanosis. No clubbing. Spleen palpable. Collapsing pulse, B.P.146/45. Loud Gibson Murmur (III) and thrill. No Mitral diastolic murmur. X-ray generalised cardiac enlargement with prominence of P.A. and main branches. No evidence of infarction in lung fields. Six blood cultures negative.
Operation 16.12.47, aged 32yrs. Short, relatively wide Ductus situated more posteriorly than usual. Wall friable and perforated at operation. Haemorrhage and death.

Post-Mortem - Mass of friable vegetations in Pulmonary Artery just proximal to bifurcation. No vegetation in Ductus itself. Two small vegetations on anterior and right posterior cusp of Pulmonary Valve. Both ventricles dilated and moderately hypertrophied.

31. A.S., female, aged 6.

No complaint other than recurrent colds. Mother had Mumps during pregnancy.
Examination - above standard height and weight. Corrigan pulse. B.P. 106/40. Well-marked signs. Aged 9yrs., roaring Gibson Murmur (III) and thrill with well-marked Mitral mid-diastolic murmur. B.P. 140/48, after exercise 160/20. X-ray moderate cardiac enlargement (+15%) - characteristic appearance, slight enlargement of L.A. Unipolar E.C.G. - within normal limits.
Operation 23.1.48, aged 9yrs. - large Ductus, tied with two silk ligatures. Evidence of very large shunt - when occluded, there was immediate rise in diastolic pressure from 70mm. to 140mm., associated with tachycardia of over 200 per minute, which quickly subsided.
Post-operative progress - uneventful. No cardiac murmurs, B.P. 125/70.
Last seen 1950, 2½ years after operation. Had been champion of school games. Heart sounds normal. Very soft Pulmonary systolic murmur (non-organic). B.P.100/60. Exercise test negative. X-ray shows heart now within normal limits regarding size. Unipolar E.C.G. voltage of Left precordial leads remains high. Otherwise normal.

32. J.S., female, aged 12.

Increasing breathlessness on exertion and fatigue. Unsuccessful attempt at ligation one year previously elsewhere.
Examination - very much underheight and underweight. Loud Gibson Murmur (III) and thrill. No Mitral mid-diastolic murmur. B.P.120/68, after exercise 150/25. X-ray heart size at upper limit of normal (+8%), enlargement of P.A. Typical pulsation on screen examination. Unipolar E.C.G. diphasic T in V5, otherwise normal.
Operation 17.2.48, aged 12 - posterolateral approach, moderate-sized Ductus tied with two silk ligatures.
Post-operative course - Loculated effusion due to adhesions. Left lung slow to re-expand. No cardiac murmurs. B.P.125/84.
Last seen 1950, 2½ years after operation. Steadily becoming stronger and has gained 2½ stones. One year after operation doing full gym, cycling. Two years after, swimming and playing Hockey. Only trouble has been mild intercostal neuralgia on left side in cold weather. Heart sounds perfect, B.P.125/74, exercise test negative. X-ray heart

showed reduction in size to -6% of predicted normal six months after operation. No further change. Unipolar E.C.G. during first six months after operation showed ST depression and diphasic T waves in leads II, V4, V5, V6 - thereafter normal.

33. M.K., female, aged 5.

Haemoptysis when aged 4. No disability until going to school. Thereafter increasing tiredness.
Examination - a little below standard height and weight. Loud Gibson Murmur (III) and thrill. Well-marked Mitral mid-diastolic murmur. B.P.105/40 Exercise test positive, B.P.135/5 after exercise. X-ray - cardiac enlargement (+35%) - appearances typical. No change during 1½ years observation. Unipolar E.C.G. - very deep Q (7mm.) and tall R in V5 and V6. Additional abnormality - congenital bilateral cavical ribs.
Operation 20.4.48, aged 6yrs. Large Ductus - 10mm. broad, tied with two silk ligatures.
Post-operative progress - uneventful convalescence. No cardiac murmurs, B.P.120/80.
Last seen 1951, three years after operation. Very well for two years after operation, then developed Primary Tuberculosis with X-ray appearance of "Epituberculosis". Heart sounds perfect, B.P. 100/70. Exercise test negative. X-ray - heart showed reduction in size after operation (+10%), but slight increase in size associated with development of Epituberculosis (+20%). Unipolar E.C.G. - reduction in voltage and disappearance of deep Q waves over left precordial leads.

34. P.H., female, aged 4.

Recurrent attacks of Asthma and Bronchitis since 1½yrs. Increasing tiredness after starting school, constantly falling asleep.
Examination - below standard height and weight. Very coarse thrill and Gibson Murmur (III), heard loudly over precordium. B.P.148/40, after exercise 170/10. X-ray slight cardiac enlargement (+20%) with prominent Pulmonary Artery. No change during two years of observation. Cardiac area +15% aged 6yrs. E.C.G. normal aged 4 (no unipolar leads). By age 6, had developed ST depression in II, V4,V5, with upright T waves.
Operation 7.5.48, aged 6yrs. Moderate Ductus, tied with two silk ligatures.
Post-operative course - uneventful. No cardiac murmurs. B.P.135/85.
Last seen 1950, 2½ years after operation - still below average height, but now above average weight. Very energetic. Chest clear. Perfect heart sounds. B.P.115/82. Negative exercise test. X-ray shows marked reduction in cardiac size (now -5%). E.C.G. one month after operation, T inversion in V5, thereafter normal apart from tall R waves over left precordial leads.

35. J.H., male, aged 5.

Recurrent chesty colds. Pallor and tiredness after starting school.
Examination - well built, above standard height and weight. Loud Gibson Murmur (II) and thrill. B.P.125/60, after exercise 140/25. X-ray - slight cardiac enlargement (+12%), appearances typical. E.C.G. normal.
Operation 14.5.48, aged 5yrs. - large, very thin-walled Ductus - Pleura over Ductus speckled as if infected.
Post-operative course - developed Empyema which necessitated rib resection one month later. Slow convalescence. Perfect heart sounds throughout. B.P.105/80.
Last seen 1950, 2½ years after operation. Still a little breathless on exertion. Otherwise fit. Well above standard height and weight. Heart sounds perfect. B.P.120/75. Exercise test negative. X-ray - heart size normal (+0%). Unipolar E.C.G. normal.

36. N.D., female, aged 1yr. 4 months.

Not gaining, breathless when feeding. "Takes a little and rests". Family history noteworthy - Older sister died as a "blue baby". Older brother (Case 48) subsequently found to have Patent Ductus also. Followed up to 5 years of age, always breathless, never able to play, recurrent respiratory infections.
Examination - aged 16 months, a little blue when crying. Long, harsh systolic murmur at Pulmonary Area with accentuated second sound. Aged 5yrs. well developed Gibson Murmur (III) and thrill, with diastolic murmur at Mitral area. B.P.105/48, after exercise 140/10. X-ray - cardiac enlargement present at 16 months with prominent P.A. and lung markings (C.T.R.56.6). Marked cardiac enlargement aged 5 (C.T.R.60, Cardiac Area +45%). Appearances typical. Heart displaced to left, recurrent atelectasis of left lower lobe. E.C.G. aged 5yrs. diphasic T waves V4, V5.
Operation 11.6.48, aged 5yrs. - large Ductus tied by two silk ligatures.
Post-operative course - syncopal in upright position for four days. No cardiac murmurs, B.P.110/84. No effusion. Very rapid improvement after operation.
Last seen 1950, two years after operation. Still below standard for height and weight. Very well. No respiratory infections. Healthy appearance. Perfect heart sounds. B.P.120/88. Exercise test negative. Signs at L. base have steadily improved. X-ray - definite reduction in heart size (two months post-operative C.T.R.55.9, one year after 53.4, two years after 51.3). E.C.G. one month after operation steep T inversion aVL, V5, V6;

Two months after operation, diphasic T waves. Thereafter normal.

37. C.L., female, aged 5.

Unfit for school owing to extreme exhaustion.
Examination - fragile child, below standard height and weight. Thrill and Gibson Murmur (II). B.P.110/45, after exercise 140/20. X-ray - considerable degree enlargement of heart (+45%). Right-sided enlargement greater than most. General displacement of oesophagus by enlarged heart. No definite increase in L.A. Screen appearance typical. E.C.G. deep Q, tall R in V4, V5.
Operation 29.6.48, aged 6yrs. Large Ductus (10mm. by 10mm.), ligated by two silk ligatures.
Post-operative course - uneventful. No cardiac murmurs. B.P. 120/85.
Last seen 1950, 2½ years after operation - Not easily tired, goes for long walks. Now above standard height and weight. Heart sounds perfect, B.P.110/74. Exercise test negative. X-ray - steady reduction in heart size now (-5%). E.C.G. for three months after operation showed ST depression with diphasic T wave in I, aVL, V4, V5, V6. Thereafter normal.

38. M.K., female, aged 4.

Slow to develop, easily tired, disinclined for exercise.
Examination - aged 4, average size for her age. Faint thrill and Gibson Murmur (I). B.P.105/65. Two years later, little change. B.P.115/50, with drop in diastolic pressure to 12 only after strenuous stair-climbing. X-ray - no increase in size of heart and no change in two years. E.C.G. normal.
Operation 1.7.48, aged 6yrs. Ductus smaller than usual.
Post-operative course - uneventful, apart from recurrence of continuous murmur ten days after operation and faint thrill 13 days later. B.P. 115/62, after exercise 165/30.
Last seen 1951, three years after operation. Following operation "a different child", playing and skipping and never tired. Six months after operation heart sounds normal - soft venous hum in neck. B.P.110/65. Exercise test negative. Ductus had apparently closed. Three years after operation, heart sounds perfect, B.P.120/85. Negative exercise test. X-ray, heart size remains normal (+0%). No increased pulsation. E.C.G. normal.

39. J. McK., female, aged 7.

Full description P. 279.

40. K.McH., female, aged 7.

Easily tired since starting school. Spina bifida operation at birth.
Examination - above standard height and weight. Well marked Gibson Murmur (II) and thrill. B.P.120/60, after exercise 170/20. X-ray, slight cardiac enlargement (+10%). Very marked scoliosis of Thoracic spine. Prominent P.A. and hilar vessels. E.C.G. normal.
Operation Aug. 48, aged 6yrs. Very large Ductus, more than 10mm. wide, ligated with two silk ligatures.
Post-operative progress - Post-operative haemothorax. No cardiac murmurs. B.P.120/80.
Last seen 1950, two years after operation. Very well - dancing and gym. Posture improved. Still above standard development. Heart sounds normal, B.P.112/88. Exercise test negative. X-ray - Scoliosis less marked. Heart size well within normal limits (-12%). E.C.G. normal.

41. E.A., female, aged 9.

No complaint at time, but Mother realised in retrospect that she had been easily tired. Older sister died of bacterial endocarditis ?congenital heart.
Examination - Healthy looking girl, below standard height and weight. Well-marked thrill and Gibson Murmur (II) with mid-diastolic murmur at Mitral area. B.P.124/58, after exercise 145/20. X-ray, minor degree of cardiac enlargement (+15%). Typical appearance, slight enlargement of Left Atrium. E.C.G. normal.
Operation 7.10.48, aged 9yrs. Short, wide Ductus fully 10mm. in diameter, tied by two silk ligatures.
Post-operative course - collapse of left lung with pneumothorax and haemothorax. No cardiac murmurs. B.P. 125/80.
Last seen 1950, 1½ years after operation - much more fit - doing better at school. Still below standard weight, but has gained 9lbs. Soft Pulmonary systolic murmur - heart sounds otherwise normal. B.P. 125/78, after exercise 170/70. X-ray - cardiac size reduced (-1%). L. border still straight. E.C.G. tall R in V5, V6 (55 and 45mm. respectively). Otherwise normal.

42. A.E., female, aged 25.

Always well. Plays tennis, swims and rides. Wishes ligation of Ductus.
Examination - Well developed young woman. Height 5ft. 4ins., weight 121 lbs. Marked Sinus Arrhythmia. Gibson Murmur (II). No Mitral diastolic murmur. Heart displaced to left. Cardiac area increased (+15%), though T.D. normal (C.T.R.45.7). L.V. appears enlarged. P.A. increased. E.C.G. normal.

Operation 14.10.48, aged 25yrs. - Ductus rather smaller than usual, 7.5mm. broad, 10mm. long.
Post-operative course - Small effusion - not aspirated. Recurrent laryngeal paralysis, which recovered after four months. No cardiac murmurs. B.P. 115/75.
Last seen 1949, one year after operation. Very well. Three months pregnant. Soft Pulmonary systolic murmur. Heart sounds otherwise normal. B.P.108/75. X-ray - diminution in heart size (+0%) - small pericardial adhesion to fourth rib. Heart displaced to left. P.A. remains prominent. E.C.G. normal.
Subsequent progress - 26.3.50 - First child born - long labour due to uterine inertia; remained well. Pulse at end of labour 80 per minute R.20.

43. J.C., male, aged 13.

Playing Football till four years before admission. Increasingly breathless and tired.
Examination - Below standard height and weight. Diffuse precordial pulsation with Gibson Murmur(III) and thrill. B.P.120/44, after exercise 190/5. X-ray - increase in cardiac size (+30%). Appearance typical. E.C.G. ½mm. ST depression, upright T, lead II. R 13mm., 1mm. ST depression with inverted T in aVF. Precordial leads normal apart from high voltage. Deep S in V1 (30mm.), tall R V5 (25mm.). ? Left Ventricular Hypertrophy.
Operation 6.12.48, aged 13yrs. Large Ductus, 10mm. diameter, ligated with two silk ligatures.
Post-operative course - uneventful. No cardiac murmurs. B.P.105/75.
Last seen 1950, two years after operation. Growing well. Very active. Never tired. Feels better in every way. Cycled 85 miles three months after operation. Heart sounds perfect. Second sound at base not accentuated. B.P.115/75. Exercise test normal. X-ray - heart size a little reduced but still above normal. E.C.G. is unusual and now suggestive of Right Ventricular Hypertrophy, with delayed ventricular activation time in V1 - 0.06 sec. (pre-operative 0.02 sec.), ST depression and T inversion in III. ST depression and diphasic T in aVF.

44. S.C., female, aged 6.

Tiredness and pallor since birth. Frequent bronchitis.
Examination - Poorly nourished, well below standard height and weight. Loud, roaring Gibson Murmur (III) and thrill. B.P.122/58, after exercise 160/20. X-ray, Cardiac Size within normal limits (+0%) - appearance typical. E.C.G. 1mm. ST depression lead II and aVF. Precordial leads normal.
Operation 25.10.48, aged 6yrs. - Large, thin-walled Ductus - ligated with two silk ligatures.

Post-operative course - uneventful. No cardiac murmurs. B.P.130/75.
Last seen 1949, one year after operation. Uncared for - still poorly nourished. Heart sounds normal, B.P.125/75. Exercise test negative. X-ray - size remains within normal limits (-4%). E.C.G. normal.

45. J.S., female, aged 14.

Full description P. 256.

46. D.F., male, aged 7.

Full description P. 264.

47. M.F., female, aged 14.

No complaint but in retrospect realised that she had always been easily tired.
Examination - Below standard height and weight. Faint thrill and soft continuous murmur (I) in 1st, 2nd, 3rd intercostal spaces to left of Sternum. Second sound at Pulmonary area not accentuated. Short mitral mid-diastolic murmur. Collapsing pulse, B.P.130/38, after exercise 185/5. X-ray - size of heart upper limit of normal (+12%). Shape suggests rather more Right Ventricular enlargement than usual. E.C.G. horizontal heart, within normal limits.
Operation 4.2.49, aged 14yrs. - Ductus of average size - ligated with two silk ligatures.
Post-operative course - little immediate post-operative rise. Uneventful convalescence.
Last seen 1951, two years after operation. Much livelier, able to dance all evening, whereas previously she felt too tired. No increase in height (5ft.) but has gained half a stone in weight. Perfect heart sounds. B.P.110/55, after exercise 180/50. X-ray, little change in size or shape (+10%). Pulsation within normal limits. E.C.G. normal.

48. J.D., male, aged 8.

Patent Ductus found on routine examination of family of N.D. (Case 36). Had always been pale and thin since Scarlet Fever aged 3yrs.
Examination - A pale, introspective child, a little below standard height and weight. Had been much impressed by the improvement in his sister (Case 36) following operation and knew that he had the same heart lesion. Continuous murmur present on most occasions but softer (I) and more highly pitched than usual. When lying quietly, murmur appeared to be systolic only, but continuous quality brought out by exercise. B.P.115/50, after exercise 150/5. X-ray showed characteristic appearance (size +12%). E.C.G. normal.

Operation 17.2.49, aged 9yrs. Wide Ductus (more than 10mm.) with apparently a thick wall. Ligated with two silk ligatures.
Post-operative course - small area consolidation, left upper lobe with haemoptysis. No cardiac murmurs. B.P.110/80.
Last seen 1950, 1½ years after operation. Immediately after operation was very well and active, but four months later developed Right Pleural Effusion (presumably tuberculous). Made a good recovery from this. X-ray showed initial decrease in heart size (+0% after one month) and marked decrease in lung congestion. Following pleural effusion slight increase in heart size again to +12%. E.C.G. normal. Heart sounds have remained normal. B.P. 120/75 with negative exercise test.

49. S.S., female, aged 8.

Easily tired and breathless since 1½ years of age, increasingly so since 6 years. Not fit for ordinary school.
Examination - A little below standard height and weight. Well-marked signs, with thrill and Gibson Murmur (II). Systolic and diastolic murmurs audible at apex. B.P. 120/50, after exercise 170/12. X-ray - heart enlarged (+20%) and displaced to left, appearances otherwise characteristic. Slight enlargement of Left Atrium. E.C.G. - precordial leads show tall R in V5 and V6 (45 and 68mm. respectively) - and deep T inversions V1 to V4.
Operation 10.3.49 aged 8yrs. - Ductus 10mm. broad - pleural cavity obliterated by fibrous adhesions, dating from severe respiratory infection age 18 months.
Post-operative course - Convalescence slow because of loculated effusion but no return of cardiac murmur. B.P. 125/85.
Last seen 1950, one year after operation. General health much improved, never tired or breathless now. Has gained a stone in weight since operation - now within normal limits regarding height and weight. Heart sounds perfect. B.P.115/85 - exercise test negative. X-ray shows reduction in heart size to normal limits (+4%). Left Atrium no longer enlarged. E.C.G. shows reduction in voltage of precordial leads including T waves, which are now upright in V4, V5, V6.

50. M.S., female, aged 20 months.

Easily tired, looks blue when walking.
Examination - poorly nourished. Harsh systolic murmur with character of Gibson Murmur. B.P.92/38. X-ray - cardiac enlargement with prominent P.A. E.C.G. normal. Observed for three years - failure to thrive, losing weight. Typical G.M.(II) developed aged 3½yrs. X-ray showed increasing

cardiac enlargement. E.C.G. unipolar leads normal with deep Q waves and tall R over Left Precordial leads.
Operation 26.3.49 aged 4yrs. Large Ductus, ligated with three silk ligatures.
Post-operative course - uneventful. No cardiac murmurs. B.P.120/80.
Last seen 1950, one year after operation. Completely changed. Runs about playing all the time. Never breathless or blue. Has gained 10½lbs. since operation (weight now 41 lbs.). Heart sounds perfect. B.P.115/80. Exercise test negative. X-ray - reduction in heart size (pre-op. +40%, now +8%). E.C.G. normal, reduction in Q waves to left of precordium.

51. M.McC., female, aged 8.

Easily tired, breathless on exertion since going to school.
Examination - below standard height and weight. Well marked Gibson Murmur (III) and thrill. Continuous murmur heard all over precordium including apex. B.P.125/50, after exercise 160/10. X-ray - slight generalised cardiac enlargement (+20%). L.A. unusually prominent for heart size. E.C.G. high voltage, otherwise normal.
Operation 9.5.49, aged 8yrs. Ductus 7.8mm., ligated with three silk ligatures.
Post-operative course - no effusion. No cardiac murmurs. B.P. 120/70.
Last seen 1951, two years after operation. Much improved. Now like other children. Still below standard height but nutrition good. Heart sounds perfect - no mitral diastolic murmur. B.P.115/80, after exercise 170/82. X-ray - gradual reduction in heart size, now +0%. L.A. remains enlarged. Pulsation normal. E.C.G. normal limits.

52. J.L., male, aged 19.

Admitted ?bacterial endarteritis: two attacks of Pneumonia in previous month, treated with Penicillin. Yellow colour and feverish one month. Always undersized, thin and easily tired.
Examination - thin, undernourished. Height 5ft.5ins. weight 6st. 13lbs., café-au-lait complexion. Gibson Murmur (I-II). B.P.115/60, occasional attacks of bradycardia. Signs consolidation Left upper lobe. B.S.R. 68mm./hour. Blood cultures (6) negative. X-ray - slight cardiac enlargement (+15%), prominent P.A. E.C.G. normal voltage. Horizontal heart, inversion T in aVL. No other signs of Left Ventricular Hypertrophy.
Observed for two months. Gibson Murmur more marked (II) and thrill, B.P.130/60. X-ray - gradual reduction in heart size to -5%. Opacity in lung clearing. E.C.G. no change.

Operation 16.5.49, aged 19yrs. Very thin-walled Ductus 10mm. wide, 10mm. long. Pulse irregular during operation. Cardiac arrest immediately after ligation of Ductus.
Post-Mortem.
Heart - moderate hypertrophy of Left Ventricle.
Pulmonary Artery - enlarged, plaque-like vegetations extending almost to bifurcation. Intima around Ductus free.
Inferior cardiac branch of Vagus caught in ligature around Pulmonary end of Ductus.
Microscopic examination - a) Pulmonary Artery. Arrested Pulmonary Arteritis with healing.
b) Lung. Several areas of infarction. Appearance of arteries suggests previous bacterial infection affecting arteries.

53. F.J., female, aged 4.

Lack of energy, easily tired one year.
Examination - Below standard height and weight. Roaring Gibson Murmur (III) and thrill with Mitral mid-diastolic murmur. B.P.110/60, after exercise 160/30. X-ray - slight generalised enlargement (+10%). Slight enlargement of L.A. E.C.G. high voltage in Left Ventricular leads, otherwise normal. Other congenital abnormality - Spina Bifida.
Operation 6.6.49, aged 5yrs. Tissue around Ductus very tough, suggesting previous infection. Ductus tied with three ligatures. Recurrent Laryngeal Nerve nipped.
Post-operative course - Partial laryngeal paralysis, which cleared after six months. Loculated haemorrhagic effusion. Protracted convalescence.
Last seen 1950, 1½ years after operation. Very well, never tired. Nutrition improved. Now average height and weight. Slightly keloid scar. Heart sounds perfect. B.P.112/75. Exercise test negative. X-ray - Left border remains straight, but gradual reduction in size (now +0%). L.A. remains slightly increased. E.C.G. normal limits.

54. J.A., female, aged 8.

C.H.D. recognised by School Medical Service. No disability.
Examination - well-developed girl, above standard height and weight. Loud Gibson Murmur (II) with diastolic intensification. No Mitral mid-diastolic murmur. B.P.120/60, after brisk exercise 175/10. X-ray - slight cardiac enlargement (+20%). P.A. enlarged. Pulsation on screen examination was within normal limits. E.C.G. in precordial leads, T inversion extends further to left than usual. Otherwise normal.
Operation 13.6.49, aged 8yrs. Average sized Ductus (thin-walled) ligated by two silk ligatures.
Post-operative course - uneventful. No cardiac murmurs. B.P.125/85.

Last seen 1950, one year after operation. Seems to have less energy than before operation. Quiet heart, perfect heart sounds. B.P.115/85, exercise test negative. X-ray heart still a little large (+12%). E.C.G. - unusual T waves in precordial leads. T diphasic with steep inversion (5mm.) V4.

55. H.W., female, aged 5.

Easily tired and readily breathless since a toddler.
Examination - well below standard height and weight. (sister, one year younger, is taller and heavier). Well-marked signs - Gibson Murmur (II) and thrill. Mitral mid-diastolic murmur. B.P. 120/40, after exercise 150/10. X-ray - considerable cardiac enlargement (+30%) involving Right Ventricle to greater extent than Left. L.A. increased. Vascularity of lung fields much increased. E.C.G. Deep S in V1 and tall R in V5 - otherwise normal. Observed one year. No change in signs.
Operation 28.7.49, aged 6yrs. Large Ductus with mild fibrosis medial side of D. Ligated with two silk ligatures.
Post-operative course - uneventful. No cardiac murmurs. B.P.120/90. Was very fit for three months after operation. Then developed tonsillitis, septic hand and was admitted in extreme respiratory distress and severe congestive heart failure. Signs of consolidation right base. Blood Culture grew Pneumococci. Gross albuminuria. Long severe illness.
Last seen 1950, one year after operation. Much improved. Nutrition better, but still a little below standard. Heart sounds normal. B.P.120/90. X-ray - some decrease in size compared with before operation (now +10%). P.A. remains prominent. L.A. now normal. E.C.G. during Pneumococcal septicaemia and Nephritis showed signs of Left Ventricular Hypertrophy, with ST depression, T inversion in I, aVL, V4,V5,V6, Left Bundle Branch Defect and deep Q waves in V1 and V2 (38mm.) suggestive of myocardial damage. Thereafter gradual return to normality. E.C.G. one year after operation normal, no evidence of Left Ventricular Hypertrophy.

56. A.B., female, aged 4.

No disability apart from faints during breath-holding attacks.
Examination - well above standard height and weight. Loud Gibson Murmur (II) and thrill. No Mitral mid-diastolic murmur. B.P.108/60, after exercise 130/15. X-ray - slight cardiac enlargement (Cardiac Area +5%, C.T.R.51.7), brisk pulsation on screen examination. P.A. enlarged. E.C.G. unipolar leads normal.
Operation 19.9.49, aged 4yrs. Average-sized Ductus (10mm. broad). Ligated with two silk ligatures.

Post-operative course - uneventful. Developed venous hum during first two weeks. No cardiac murmurs. B.P.115/80.
Last seen 1950, three months after operation. Well. Now unable to faint when she holds her breath as before. Nutrition good. Heart sounds perfect. B.P.115/80. Exercise Test negative. X-ray - cardiovascular shadow normal apart from some fullness in region of Pulmonary Artery. Cardiac size reduced (-6%). E.C.G. normal.

57. S.S., female, aged 12.

Always slow and easily tired. Severe recurrent respiratory infections (off school for 18 months).
Examination - above standard height but underweight. Diastolic thrill and loud Gibson Murmur (III) with accentuated P2. Systolic and diastolic murmur audible at Mitral area. B.P.125/50, after exercise 165/5. Heart size within normal limits. Appearance otherwise typical. E.C.G. tall R waves over Left Precordial leads. Otherwise normal.
Operation 29.9.49, aged 13yrs. Very large Ductus. Ligated with two silk ligatures.
Post-operative course - Massive collapse of left lung on day after operation, which cleared quickly with physiotherapy. No cardiac murmurs. B.P. 130/85.
Last seen 1950, one year after operation. Attending school regularly (four miles daily). Country dancing. No recurrence of chest infection. Now well above standard height and weight. Posture improved. Heart sounds perfect. B.P.120/76. Exercise Test negative. X-ray reduction in cardiac size (C.A. -15%). E.C.G. reduction in voltage. Normal.

58. S.W., female, aged 5.

Full description P. 271

59. N.B., female, aged 17.

Few complaints. Always thin. Subject to Epistaxis.
Examination - Ht. 5ft. 3ins., Wt. 7st. 8lbs. Thin. Well-marked signs. Gibson Murmur (III) and thrill. P2 accentuated. Waterhammer pulse. B.P.135/40, after mild exercise 205/5. X-ray - cardiac enlargement (+28%), large Pulmonary Artery and congested lung fields. Left Atrium enlarged. E.C.G. - Deep Q waves in V6 (7mm.) and high voltage. Otherwise normal.
Operation 13.12.49, aged 17yrs. Large Ductus, ligated with three ligatures.
Post-operative course - Effusion requiring aspiration. Severe epistaxis on fourth day. No heart murmurs. B.P.130/90.
Last seen 1950, six months after operation. Never tired. No increase in height or weight. No murmurs. P2 remains accentuated. B.P.120/80,

after exercise 120/82. X-ray shows reduction in cardiac size, now normal (+8%), and reduction in Pulmonary vascularity. Left Atrium still enlarged. Unipolar E.C.G. normal, disappearance of deep Q waves in left precordial leads.

60. W.C., female, aged 9.

No complaint, but in retrospect realised to have been breathless on exertion.
Examination - Below average height and weight, but otherwise appears fit. No thrill. Harsh Gibson Murmur (II). P2 accentuated. No mid-diastolic murmur at Mitral area. B.P.130/75, after brisk exercise 170/30. X-ray - slight cardiac enlargement (+15%). Left border straight. Slight enlargement of Left Atrium. Screen appearance typical. Unipolar E.C.G. normal.
Operation 27.1.50, aged 9yrs. Average size Ductus. Little rise in diastolic pressure after ligation.
Post-operative course - uneventful. No cardiac murmurs. B.P.105/80.
Last seen 1950, 11 months after operation. Well, even more fit than before (previously breathless when cycling). Still below standard height and weight. Heart sounds perfect. P2 normal. B.P.118/82. Exercise test normal. X-ray - reduction in cardiac size (now +0%), decrease in Pulmonary vascularity. Left Atrium no longer enlarged. Screen examination normal. Unipolar E.C.G. further reduction in voltage. Normal.

61. A.G., male, aged 11.

Breathless on exertion. Frequent colds.
Examination - Thin, undernourished. Well below standard height and weight. Slow pulse varying 60 to 80 per minute, thrill and loud Gibson Murmur(III). Diastolic component unusually pronounced especially when slow. Mitral mid-diastolic murmur. B.P. 128/60, after exercise 150/110. X-ray - generalised cardiac enlargement (+45%), enlargement of Left Atrium, increased vascularity of lung fields. Heart less active and pulsation in great vessels less than usual. E.C.G. normal.
Operation 10.2.50, aged 11yrs. Narrow Ductus, only 3mm. in diameter. Ligated with two silk ligatures.
Post-operative course - Haemorrhagic effusion followed by serous effusion requiring aspiration on several occasions. No cardiac murmurs. B.P. 125/80.
Last seen 1951, one year after ligation. Less easily tired and less breathless. Little increase in height or weight, still below average. Has residual Recurrent Laryngeal Paralysis, compensated. Soft, Pulmonary systolic murmur remains (non-organic). B.P.120/80. Exercise test normal. X-ray - heart size now within normal limits (+10%). Hilar shadows less prominent. Some loss of translucency Left midzone. Unipolar E.C.G. normal.

62. J.D., female, aged 9.

Always easily tired, pale and thin.
Examination - Well below standard height and weight. Thrill and Gibson Murmur (II), maximal 2nd space but heard over 2nd, 3rd, 4th spaces. P2 accentuated. Mitral mid-diastolic murmur. B.P.110/64, after brisk exercise 145/45 (very good exercise tolerance). X-ray - upper limit of normal regarding size (+12%). Appearance typical. E.C.G. normal.
Operation 13.2.50, aged 9yrs. Average Ductus, ligated with two silk ligatures.
Post-operative course - Traumatic Laryngitis. Venous Hum between 9th and 12th days. No other murmurs. No alteration in B.P. (120/80).
Last seen 1951, one year after operation. Never tired. Has gained half a stone in weight. Perfect heart sounds. B.P.115/75. X-ray - no change in cardiac size. Big reduction in size of Pulmonary Artery, now almost normal. E.C.G.normal.

63. I.B., female, aged 7.

Attacks of tiredness and breathlessness since 2 years.
Examination - Average nutrition. Pale, tired-looking child. Loud Gibson Murmur (II) and faint thrill. Mitral mid-diastolic murmur. B.P.115/45, after exercise 160/10. X-ray - globular heart. C.A.+30%, appearances typical. E.C.G. tall R waves in V5,V6. Otherwise normal.
Operation 3.3.50, aged 7yrs. Ductus 7.5mm. broad, ligated with three silk ligatures.
Post-operative course - small effusion aspirated. No cardiac murmurs. B.P.120/75.
Last seen 1951, 14 months after operation. Never tired. Looks much more robust. Above standard height and weight. Scar became a little keloid after operation but settled with radiotherapy. Heart sounds perfect, B.P.120/68. Exercise test normal. X-ray - marked reduction in cardiac size (now +0%) and diminution in lung vascularity. E.C.G. showed signs of Left Ventricular Hypertrophy with ST depression in left precordial leads one month after operation, associated with reduction in cardiac size from +30% to +8%. Thereafter normal.

64. I.H., female, aged 11.

Easily tired since infancy. Breathlessness on exertion since 5 years.
Examination - Below standard height and weight. Thrill and Gibson Murmur (III), with marked accentuation of P2. B.P.115/60, after brisk exercise 170/10. X-ray - slight cardiac enlargement (+20%), appearances consistent with diagnosis of P.D.A. Increased pulsation over Left Ventricle and Pulmonary Artery. Slight pulsation in hilar vessels. E.C.G. deep Q waves (6 and 7mm.), tall R waves (40mm.) over left precordial leads, suggestive of Left Ventricular Hypertrophy.

Operation 20.3.50, aged 11yrs. Ductus 10mm. diameter. Ligated with three ligatures.
Post-operative course - Post-operative hypertension (150//120) on second and third days after operation. Renal function normal. No murmurs. B.P. after one week 125//90.
Last seen 1951, one year after operation. Well, never tired or breathless. Has gained a stone in weight. Perfect Heart sounds. B.P.125//90, after exercise 160//92. X-ray - reduction in cardiac size to normal (+10%). Marked decrease in Pulmonary Artery. E.C.G. for three months after operation showed signs of Left Ventricular Hypertrophy - ST depression T inversion in I, V5, V6. Thereafter, reduction in voltage with disappearance of deep Q waves, seen before operation.

65. M.K., female, aged 11.

Easily tired since infancy. Breathlessness on exertion since going to school.
Examination - Average Nutrition. Well-marked signs with thrill and Gibson Murmur (III) heard widely over precordium. P2 accentuated. Mid-diastolic murmur at Mitral area. B.P.115//45, after exercise 145/10. X-ray - moderate cardiac enlargement with slight displacement of heart to left. Left border straight. Pulmonary Artery and Aorta not clearly distinguishable. Increased pulsation over heart and great vessels. E.C.G. deep Q, tall R waves over Left Precordium. Otherwise normal.
Operation 31.3.50, aged 11yrs. Ductus 10mm. diameter. Ligated with three silk ligatures.
Post-operative course - Loculated effusion anteriorly, requiring frequent aspiration. Prolonged convalescence. No murmurs. B.P.120/80.
Last seen 1950, six months after ligation. Very energetic. Has gained a stone in weight. Soft Pulmonary Systolic murmur. P2 remains accentuated. No Mitral Murmur. B.P.130/92. Exercise test negative. X-ray - reduction in cardiac size (+15%). Pulsation normal. E.C.G. reduction in voltage. Normal.

66. E.P., female, aged 6.

Recurrent respiratory infections since babyhood. Well up to time of going to school. Breathless on exertion and easily tired since
Examination - Well below standard height and weight. Very coarse signs, with pulsation in suprasternal notch and Carotids (no thrill). Continuous thrill and loud Gibson Murmur (III) heard all over precordium, maximal second and third space. P2 markedly accentuated. B.P.115/40, after exercise 150/10. X-ray - generalised cardiac enlargement (+50%) affecting Left Ventricle more than Right. Pulmonary Artery enlarged with increase in hilar shadows and Pulmonary vascularity. On screening, increased pulsation but no hilar dance. E.C.G.normal.

Operation 11.9.50, aged 7yrs. Ductus rather less than 10mm. broad. Ligated with three silk ligatures.
Post-operative course - Mild Bronchitis. No effusion or collapse. No murmurs. B.P.105/75.
Last seen 1951, six months after operation. Well, less tired and less breathless than before. Still below standard height and weight. Heart sounds perfect. B.P.108/80. Exercise Test normal. X-ray reduction in heart size to +20%, and in vascularity of lung fields. E.C.G. remains normal.

67. F.F., male, aged 16.

Always lively. No disability. Keen to be a Miner. Always small for his age (5ft. 2ins.). Nutrition below average.
Examination - Pulse slower than most. Gibson Murmur (II) with systolic intensification and double diastolic quality. P2 accentuated. Mitral mid-diastolic murmur. X-ray - heart size within normal limits (+2%), appearance typical. No Left Atrial enlargement. E.C.G. normal.
Operation 18.9.50, aged 16yrs. Ductus smaller than average, 7.5mm. diameter. Ligated with two silk ligatures.
Post-operative course - loculated effusion requiring repeated aspiration. Recurrent Laryngeal Paralysis. No cardiac murmurs. B.P.120/78.
Last seen 1951, nine months after operation. Well. No cardiac murmurs. B.P.120/75. Exercise Test negative. Further reduction in cardiac size. E.C.G. remains normal. Recurrent Laryngeal Paralysis persists.

68. M.S., female, aged 11.

Always breathless on exertion.
Examination - Below standard height and weight. Poor posture. Very gross signs. Continuous thrill and loud Gibson Murmur (III) heard all over precordium. Mitral mid-diastolic murmur. Collapsing Pulse. B.P.120/50, after exercise 140/10. X-ray - moderate cardiac enlargement(+58%) with enlargement of L.V. and L.A. Increased pulsation on screen examination. No hilar dance. E.C.G. - Trace ST depression I, II, aVF, V5, V6, suggesting L.V. Hypertrophy.
Operation 22.9.50, aged 11 yrs. Large Ductus 12mm. diameter and very short. Ligated with two silk ligatures.
Post-operative course - Loculated anterior effusion, requiring repeated aspiration. No cardiac murmurs. B.P.120/90.
Last seen 1951, six months after operation. Prolonged convalescence because of loculated effusion but gradual improvement. Has gained 11 lbs. Heart sounds perfect. B.P.120/90. X-ray shows noteworthy decrease in heart size from

+58% to +15%. Supracardiac shadow is widened to left and it is not possible to distinguish Aortic knuckle in anterior film, as it appears to merge into shadow of Pulmonary Artery(this appearance may be due to fibrotic change following effusion). E.C.G. after operation showed ST depression and steep T inversions in I,II,aVL,aVF,V4,V5,V6 - marked increase in signs of L.V.H. associated with marked decrease in heart size. E.C.Gs. at monthly intervals thereafter have shown progressive decrease in signs, now minimal.

69. H.M., female, aged 11.

Breathless on exertion since a toddler. Blue in cold weather or when crying.
Examination - Below standard height and weight. Faint thrill and Gibson Murmur (II). No Mitral mid-diastolic murmur. B.P.120/68, after exercise 160/30. X-ray - cardiac size within normal limits (+6%). Straight left border. No increased pulsation on screen. E.C.G. deep Q waves V5, V6. Otherwise normal.
Operation 28.11.50, aged 11yrs. Broad Ductus (10mm.) but very short (2-3mm.).
Post-operative course - Loculated effusion lying anteriorly and requiring repeated aspiration. Atelectasis persisted. Lung expanded following bronchoscopy. Prolonged convalescence.
Last seen 1951, four months after operation. Has gained 11 lbs. in weight. Perfect heart sounds. B.P.115/80. Normal exercise test. X-ray - lung fields still show residual opacity. Heart size not measurable on this account. E.C.G. normal.

70. A.C., female, aged 25.

Full description P. 241

71. W.H., male, aged 64.

Full description P. 252

72. J.I., male, 45-55yrs.

Conscious of heart irregularity. Not really incapacitated. Able to walk long distances and to cycle.
Examination - Well developed man. Well-marked signs of Patent Ductus with Gibson Murmur (II). No thrill and no Mitral murmur. B.P.155/65 with collapsing pulse. X-ray - considerable cardiac enlargement (+90%). L.V.H. and prominent Aortic knuckle. Considerable enlargement of Pulmonary Artery and increased vascularity in lung fields. Screen showed increased pulsation and some hilar dance. E.C.G. complex Extra-systolic rhythm.
Progress - Little change for ten years, when he took occasional convulsions with loss of consciousness.

C.N.S. no abnormality. No change in cardiac signs apart from commencing cardiac failure. Gibson Murmur persisted. Unipolar E.C.G. - evidence of Left Ventricular Hypertrophy with ST depression and steeply inverted T waves in I, aVL, V5, V6.
Prolonged PR interval 0.22 sec.
Sudden death aged 55 years in convulsion. No Autopsy.

73. C.W., female, aged 48.

Breathlessness on exertion, swelling of ankles since third child at age of 36yrs.
Examination - Average nutrition. Tinge cyanosis but Arterial Oxygen Saturation normal. Low-pitched Gibson Murmur (II). No thrill. No Mitral diastolic murmur. B.P.110/50. X-ray - generalised cardiac enlargement (+60%), with enlargement of P.A. and increase in lung vascularity. L.A. enlarged. Screen examination - increased pulsation in Aorta but not typical appearance. E.C.G. horizontal heart. High voltage. Signs of L.V.H. with ST depression and T inversion in I,aVL, V4 - V8.
Arm and leg Arterial Oxygen Saturation normal. Circulation Times normal.
Progress - no evidence of congestive failure.

74. E.R., female, aged 48.

Always well till 46 years of age. Thereafter palpitation, breathlessness on exertion, swelling of ankles.
Examination - severe congestive heart failure, initially improved with rest but relapsed. Finally cleared with Digitalis, Mersalyl, salt-free diet, Thiouracil.
Average nutrition. Waterhammer pulse. Marked pulsation over Carotids and Suprasternal Notch associated with thrill. Loud Gibson Murmur (III) and thrill propagated down left border of Sternum rather than out under clavicle. No Mitral mid-diastolic murmur. B.P.200/106. No Exercise Test given. X-ray - generalised cardiac enlargement (C.T.R.77), with prominence of L.V. and Pulmonary Artery. No calcification in Aorta. Congestion of lung fields. E.C.G. - ST depression and T inversion leads I,II,aVF,V5,V6, suggesting L.V.H.
Progress - No deterioration over six months on above regime - Digitalis, salt-free diet and Thiouracil. No congestive failure at present.

75. A.G., male, aged 47.

Full description P. 248

76. M.L., female, aged 42.

Breathless on exertion and tightness in chest from 37 years on. Swelling of ankles from 41 years.

IIb in last pregnancy.
Examination - Well-developed. Thrill and Gibson Murmur (I). No Mitral murmurs. B.P.180/100, no fall in diastolic pressure after exercise. X-ray, moderate enlargement (C.A.+18%). L.V. enlarged, P.A. slightly enlarged. Calcification in Aortic knuckle. Not usual increased pulsation in great vessels. E.C.G. - no evidence of L.V.H. in unipolar leads.
Progress - keeps well doing light housework.

77. W.J., male, 37-44yrs.

Working as Fisherman, has recently felt tightness across chest. No other complaints.
Examination - Average development. Well-marked thrill and Gibson Murmur (II). B.P.155/65, after exercise 220/20. X-ray - no cardiac enlargement. Pulmonary Artery enlarged, mainly anteriorly (Rt. oblique view). Increased pulsation in Pulmonary Artery. Appearances unusual. E.C.G. normal limits.
Progress - Aged 44yrs., changed his occupation to that of Dental Mechanic, and feels better on lighter work.

78. E.D., female, 31-40yrs.

Short of breath since 15yrs., but able for housework. Mother had Atrial Septal Defect.
Examination - Average nutrition. Gibson Murmur (I). No thrill. No Mitral murmur. B.P.120/65 - will not exercise sufficiently for test. X-ray - slight cardiac enlargement (+22%) affecting both Ventricles. Appearances typical. E.C.G. - High Voltage but no evidence of L.V.H.
Progress - no deterioration over ten years. No change in cardiac size.

79. D.C., male, aged 38.

Attacks of palpitation with breathlessness for six years. Last attack lasted five months.
Examination - Well-developed. Fast Auricular Fibrillation. Loud, rather musical Gibson Murmur (III), maximal under third rib, a little lower than usual. Systolic and Diastolic Murmurs at Mitral area. B.P. 170/55. Marked Corrigan pulse. X-ray - Heart greatly enlarged. T.D. over 20cm. C.T.R.61.4. Enlargement of L.V. and Pulmonary Artery with increased vascularity of lung fields. Screening not typical because of fibrillation. E.C.G. - Digitalis type of ST.T changes.
Progress - Digitalised. Normal rhythm restored after 9.6 GM Quinidine.
Physical signs changed - Murmur became coarser and more typical, and maximal in second space in normal rhythm, and associated with systolic and diastolic thrills. B.P.170/50, after exercise 200/10. X-ray showed slight decrease in T.D. and increased

translucency of lung fields. E.C.G. precordial leads, large amplitude initial deflections. Upstroke R notched in V4 - tall, broad R in V5, V6, with ST depression and T inversion (ST.T changes possibly due to Digitalis). Regular Rhythm maintained by regular use of Quinidine. Able to return to work as Chauffeur-gardener. Because of distance, not seen again in person, but writes after two years to say he is fit.

80. C.McL., female, aged 35.

Slightly breathless on exertion since childhood. Increasing tiredness for one year.
Examination - well-developed. Well-marked signs with continuous thrill and Gibson Murmur (III) with very loud diastolic component. Waterhammer pulse. B.P.140/50, after exercise 150/25. X-ray - considerable cardiac enlargement (+45%), affecting both Ventricles. Little Pulmonary Artery enlargement. No increased pulsation in Pulmonary Artery. Appearances atypical and in many ways more like Aortic Regurgitation and Mitral Stenosis. E.C.G. - Horizontal heart, high voltage, PR interval 0.20 sec., otherwise normal.
Progress - Unable to continue her work as Shop Assistant after 35 years of age.

81. J.M., female, 25-33yrs.

Does not admit to any incapacity: has had seven children without difficulty.
Examination - Very undernourished. Does not look well. Very forcible heart sounds. Thrill and loud Gibson Murmur (III) heard all over precordium. Long diastolic murmur at Mitral area. Corrigan pulse. B.P.125/50, after exercise 150/10. X-ray, moderate cardiac enlargement (+45%) with no increase in size in eight years of observation. Appearances typical, but pulsation in great vessels only slightly increased. E.C.G. not abnormal. High Voltage and notching of T waves as seen in many of the children.
Progress - A poor, undernourished woman, admitting to no disability. No deterioration in eight years. Goes out working in addition to bringing up family of seven. No congenital heart disease in family.

82. E.T., female, aged 35.

Always a little breathless. Worse since second pregnancy.
Examination - Undernourished, tired woman. Gibson Murmur (II). B.P.135/30. Slight cardiac enlargement on X-ray (+25%), shape suggesting Right-sided enlargement. Pulmonary Artery very prominent, including main branches. E.C.G. no unipolar leads - but 1mm. ST depression in IVF.

Progress - Last seen three months after second pregnancy - extremely tired but no congestive failure. Subsequent attempts at follow-up unsuccessful.

83. D.M., female, aged 23.

Full description P. 246

84. J.T., female, 24-27yrs.

No complaints. One child without difficulty. Found at Ante-natal Clinic.
Examination - Fit-looking young woman, with typical signs of Patent Ductus. Faint thrill and Gibson Murmur (II), propagated well out under clavicle. No Mitral diastolic murmur. B.P.140/75, after exercise 190/40. X-ray - slight generalised enlargement (+25%), appearances otherwise typical. E.C.G. showed 1mm. ST depression in I, aVF, V4, V5, V6, with no changes in T waves.
Progress - No deterioration in three years of observation.

85. M.A., female, 25-27yrs.

Slightly breathless on hills - otherwise well.
Examination - Average Nutrition. Minimal signs of Patent Ductus. No thrill. Gibson Murmur (I). B.P.115/68. X-ray size of heart upper range of normal (+12%). Hilar vessels a little prominent but lung vascularity within normal limits. Unipolar E.C.G. normal. No increased voltage.
Progress - Observed during two pregnancies. Grade IIa throughout. No change in two years' observation.

86. M.W., female, aged 24.

Has lived a sheltered life, no exercise, no schooling, Married. One child with no difficulty. Able for all her own housework.
Examination - Average nutrition. Minimal signs of Patent Ductus. Gibson Murmur (I). B.P.120/70, no drop in diastolic pressure after exercise. X-ray - slight cardiac enlargement (+30%). Shape distorted by scoliosis, right side appears prominent. E.C.G. normal.

87. J.S., female, 19-21yrs.

Always breathless on exertion.
Examination - Well-developed girl with very marked signs of Patent Ductus. Precordial systolic and diastolic thrills, widespread murmur (III) and systolic thrill in neck. Waterhammer pulse and capillary pulsation. B.P.120/45. X-ray - generalised cardiac enlargement (+33%) with typical appearances. Slight hilar dance on screen. E.C.G. normal.

Progress - Developed mild ankle oedema towards end of first pregnancy, aged 21 years.

88. L.C., female, 21-24yrs.

Always well. Grade IIa during two pregnancies.
Examination - Well-developed young woman with loud Gibson Murmur (II) and thrill. B.P.120/70, after exercise 170/10. X-ray appearances typical. Cardiac area +25%, with no change in three years of observation. E.C.G. normal.
Progress - No change in three years of observation. Since completion of this Thesis, has had Ductus ligated successfully ? infected

89. H.L., female, 22-24yrs.

Recognised at Ante-natal Clinic. Previously well.
Examination - Well-developed young woman, with minimal signs of P.D.A. Gibson Murmur (I). No thrill. B.P.115/65, after brisk exercise 150/40. X-ray - no increase in heart size. Slight increase in Pulmonary Artery and in hilar vessels. E.C.G. normal.
Progress - Two pregnancies without disability. First child died in a cyanotic attack on second day. ? congenital heart disease Second normal.

90. C.R., female, aged 18.

Increasing breathlessness for six months.
Examination - Very overweight. Marked continuous thrill and loud Gibson Murmur (II), though not harsh. No Mitral diastolic murmur. B.P.120/55, after exercise 170/10. X-ray - slight cardiac enlargement (+12%) - appearances typical apart from screen examination. No increased pulsation. E.C.G. High voltage, otherwise normal.
Progress - Refused operation. Improved with obesity diet.

91. A.E., female, 13-15yrs.

Always disinclined for exercise. Likes to laze about.
Examination - Tall, but a little below standard weight for her age. Grade I Gibson Murmur. Occasionally murmur appears systolic only when she is resting, but quickly becomes continuous with exertion or excitement. Continuous quality also brought out by lying flat. B.P.120/58, after exercise 170/35. X-ray - slight cardiac enlargement (+12%) with prominent Pulmonary Artery and increased lung vascular markings. Screen appearance typical. E.C.G. normal.
Progress - No deterioration during two years of observation. Has been ligated successfully since completion of Thesis.

92. I.J., female, 9-15yrs.

Always easily tired and breathless on exertion.
Examination - Well below standard height and weight. Purulent nasal discharge, very resistant to treatment (Atrophic Rhinitis). Grade II Gibson Murmur and thrill. B.P.128/76, after exercise 160/10. X-ray - slight cardiac enlargement (+12%), appearance typical of Patent Ductus. E.C.G. normal.
Progress - Ligation of Patent Ductus not undertaken because of infected condition of nose. Has only been fit to attend Special School, but on the whole is better as she grows older. No change in heart size during six years of observation. At 15 years of age no increased pulsation on screen examination. Appearances otherwise typical. Unipolar E.C.G. normal voltage. No L.V.H.

93. J.R., male, aged 9.

Always thin, and breathless on exertion.
Examination - Backward mentally. Hands tend to be cyanosed (peripheral cyanosis), most marked when pulse is unduly slow. Pulse frequently slow (60 per minute), and then there appears a pause between Diastolic and Systolic murmurs, i.e., at end of diastole. Gibson Murmur typical (Grade II) with thrill when heart is speeded up. X-ray - moderate enlargement (+30%) - Pulmonary Artery rather less prominent than usual. Little increased pulsation over heart and great vessels. E.C.G. high voltage. Otherwise normal.
Progress - Ligation not undertaken because of mental defect.

94. M.N., female, 6-11yrs.

Blind from birth, because of bilateral developmental defect (not cataract, no history of German Measles in pregnancy). Recurrent respiratory infections. Otherwise well.
Examination - Well-developed, above standard height and weight. Well-marked signs of Patent Ductus. Faint thrill and Gibson Murmur (II). B.P.105/56, Exercise Test not satisfactory because of blindness. X-ray - slight generalised enlargement (+16%) with typical appearance. E.C.G. normal.
Progress - Signs of Bronchiectasis at Right base with recurrent collapse. No deterioration in condition in five years' observation. Heart size if anything has become less. Awaiting ligation.

95. J.G., male, aged 7.

Always a little breathless. ? Petit Mal from 3 years of age.
Examination - Well-developed boy. Gibson Murmur (II) heard all over precordium, associated with thrill at the base. B.P.110/45, after exercise 140/25.

X-ray - moderate cardiac enlargement (+30%) with typical appearance. No unipolar E.C.G.
Progress - Mother unwilling for ligation meantime.

96. A.H., female, 7-9yrs.

No disability. C.H.D. noticed during intercurrent illness.
Examination - Average nutrition. Gibson Murmur (I). B.P.125/70, after brisk exercise 165/30. X-ray - slight generalised enlargement (+12%). P.A. enlarged, lung vascularity increased. Typical pulsation on screen. E.C.G. normal.
Progress - Gibson Murmur less obvious and latterly only heard in supine position. No change in X-ray. ? closing Ductus

97. J.L., female, aged 6yrs.

Recurrent respiratory infections since going to school.
Examination - Average nutrition. Soft Gibson Murmur (I). B.P.108/60. X-ray appearance typical (cardiac area +15%). Additional congenital abnormality - bilateral cervical ribs. No unipolar E.C.G.
Progress - Subsequently ligated elsewhere.

98. E.L., male, 5-6yrs.

No disability. C.H.D. recognised by home doctor.
Examination - A little below average height and weight. Soft Gibson Murmur with diastolic component predominant, somewhat variable. Second sound accentuated, diastolic shock and variable diastolic thrill in second space. B.P.110/55, after exercise 140/20. X-ray - appearances not quite typical, rather more right-sided enlargement than usual. Cardiac area +20%. Increased pulsation over L.V. and to lesser extent in P.A. and Aorta. E.C.G. unipolar leads normal.
Progress - No change during one year of observation.

99. E.F., female, 5-6yrs.

Little incapacity. C.H.D. recognised by School Medical Service.
Examination - Below standard nutrition. Gibson Murmur (II) and slight thrill. B.P.125/75, after exercise 145/20. Typical X-ray appearance, with little cardiac enlargement (+12%). Normal E.C.G.
Progress - Awaiting ligation.

100. A.B., male, aged 5.

Recurrent bronchitis since infancy.
Examination - Up to standard height and weight. Variable Gibson Murmur (II). Loud systolic murmur and thrill third space to left of Sternum. Mid-

diastolic Murmur at apex. Blowing parasternal diastolic murmur, becoming continuous with the systolic murmur below the clavicle. X-ray - slight generalised enlargement (+25%), more right-sided than usual. P.A. enlarged. Increase in lung vascular markings. Screening, not the usual activity seen in P.D. E.C.G. high voltage, normal.
Progress - Observation as P.D.A. complicated by Ventricular Septal Defect.

101. R.B., male, aged 5.

Easily tired, subject to colds.
Examination - Above standard height and weight. Slight thrill and Gibson Murmur (II). B.P.100/60, after exercise 125/40. X-ray - no cardiac enlargement, appearances typical. E.C.G. - QRS 0.1 sec. in V1. Otherwise normal.
Progress - Awaiting ligation.

102. E.McI., female, 2-5yrs.

Difficulty with feeding as a baby, easily tired.
Examination - Well below average size. Gibson Murmur (II) and thrill. Mid-diastolic murmur at Mitral area. B.P.105/50. X-ray - Heart size normal, prominent right border. L.A. enlargement. Increase of lung vascularity. Increased pulsation L.V. but not quite typical. E.C.G. - High Voltage. Normal.
Progress - Increasing disability at 4½yrs., breathless on exertion. Little change in physical signs. Positive Exercise Test elicited at 4yrs. Awaiting ligation.

103. J.C., female, aged 4.

Healthy child. No disability.
Examination - Above standard height and weight. Loud Gibson Murmur (III) and thrill. B.P.135/40, after exercise 160/10. X-ray - cardiac enlargement (+20%). L.V. prominent, appearances typical. E.C.G. - early evidence of L.V.H.
Progress - Ductus successfully ligated since completion of this Thesis.

104. E.McD., female, 3-4yrs.

Recurrent bronchitis, tiredness and breathlessness.
Examination - Average nutrition. Systolic thrill and loud Gibson Murmur (II) heard widely over precordium. B.P.110/50, after exercise 160/40. X-ray - slight generalised cardiac enlargement(+10%), appearances typical. E.C.G. normal.
Progress - Awaiting ligation.

105. M.C., female, 3-4yrs.

Breathlessness on exertion.
Examination - Good nutrition. Murmur not quite

typical, has quality of Gibson Murmur - long reverberant systolic and short diastolic murmur, but not quite continuous. P2 much accentuated. B.P.110/60. X-ray appearances characteristic, apart from screening. E.C.G. normal.
Progress - Gibson Murmur (II) became definite aged 4½yrs. Ductus ligated successfully since completion of Thesis.

106. M.P., female, aged 3.

Recurrent colds, blue when coughing.
Examination - Average nutrition. G.M.(II) and systolic thrill. B.P.110/58, after exercise 130/30. X-ray appearances typical, with minor degree of cardiac enlargement. E.C.G. - High Voltage. Normal.
Progress - Awaiting ligation. Sister (Case 66) has already had ligation of P.D.A.

107. E.McC., female, 2-3yrs.

Breathless on exertion. Recurrent colds.
Examination - Well up to standard. Gibson Murmur(II) with widely split and accentuated P2. B.P.110/55, no drop in diastolic pressure after exercise. X-ray - no enlargement. Prominent P.A. Screening not typical. E.C.G. normal.
Progress - No change in one year's observation. Sister (Case 51) has already had ligation of P.D.A.

108. D.C., male, 2-4yrs.

C.H.D. recognised during Measles. No disability.
Examination - Well nourished. Gibson Murmur (II). No thrill. B.P.90/50, after exercise 110/20. X-ray - slight cardiac enlargement(+22%). No increased pulsation on screen examination, but otherwise typical. E.C.G. normal limits.
Progress - Murmur has become more definite during observation. No deterioration in condition.

109. P.M., male, 2-3yrs.

A little blue when tired and cold.
Examination - Poorly nourished. Very loud reverberant systolic murmur heard widely over base, appears to extend into diastole in supine position. Thrill palpable second and third spaces to left of Sternum. X-ray shows large heart (C.T.R.58%), active on screening but not quite typical. P.A. increased as is lung vascularity. No hilar dance. E.C.G. - Horizontal heart, high voltage. Deep Q waves Left Precordium.
Progress - Not thriving well. Gibson Murmur (IV) and continuous thrill developed aged 3yrs. Signs unusually coarse for this age.

110. M.M., female, 9-15 months.

No disability.
Examination - Average nutrition. Systolic thrill and G.M.(II) at base. B.P.100/40. X-ray - Heart enlarged to left. Unusual notch in Rt. border on P.A. and Rt. border bulges at unusually high level in left anterior oblique view. E.C.G. normal limits.
Progress - Heart always rapid. Attacks of tiredness associated with rapid pulse. Little change in six months' observation.

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